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HIGHWAY RESEARCH RECORD

Number 318

8

Mass Transportation

8 Reports

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HIGHWAY RESEARCH RECORD

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Mass Transportation

8 Reports

Subject Area

84 Urban Transportation Systems

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DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING

WASHINGTON, D.C. 1970

Standard Book Number 309-01817-X

Price: $2.40

Available from

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Foreword

This RECORD contains a series of papers by various authors focusing on various aspects of mass transportation. The papers by Deen, Goehler, Schneider, and Ferreri focus on the current as well as future research needs as respects mass transportation. In general terms, these papers discuss the basic issues facing mass transportation, service aspects, marketing aspects, and hardware.

The second set of papers by Vuchic, Howson and Heathington, Vitt et al., and Wilson et al. are more conceptual in nature. Vuchic, for example, discusses his proposed Minicar Transit System (MTS), which incorporates 2 concepts: (a) a specially designed vehicle for urban travel and (b) fleet operation, i.e., renting of vehicles by the users for one or more trips.

Howson and Heathington, in their paper, review several techniques that have been used for the routing and scheduling of demand-actuated transportation systems. Such routing and scheduling techniques have been used in the computer simulation of these systems. The purpose of this paper is to bring together various proposed methods and to point out the similarities, differences, and possible limitations of each. Specific attention is directed toward work at Northwestern, M.I.T., and WABCO with a discussion of current work under way at the General Motors Research Laboratories.

The paper by Vitt, Bauer, Canty, Golob, and Heathington generally discusses the psychological scaling techniques of paired comparison and semantic scaling and shows how they may be adapted to the transportation system design process to provide the designers with more comprehensive and more structured information about the importance users place on various characteristics of a new transportation system.

Wilson, Sussman, Higonnet, and Goodman discuss the computer-aided routing system (CARS), which is a transportation system designed to produce a taxi-like service at a mass transit cost. This system allows potential passengers to request service from their homes by telephone, those calls being processed by a central computer facility.

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Mass Transportation Research: The Basic Issues

THOMAS B. DEEN, Alan M. Voorhees and Associates, Inc.

•LESS THAN 2 YEARS AGO, the U.S. Department of Housing and Urban Development spent more than $1 million developing a program of research for urban mass public transportation. More than 300 potential research projects were identified and evaluated—projects ranging from improved suspension components for rapid transit vehicles to complete new automatic personal rapid transit systems. The program recommended included expenditure of almost $1 billion over the next 5 to 15 years or, say, an average of $100 million per year. This may be compared with $30 million actually appropriated for research, development, and demonstration this year. Much of this actually went for demonstrations involving existing technology. It also may be compared with the latest Administration bill, which includes $500 million for transit research over the next 10 years, or about one-half that recommended in the HUD research program.

After such an extensive and exhaustive review and recommendations concerning transit research, it would appear that little could be added to the subject at this point by an individual writing in a brief paper. However, the sharp conflict between identified needs (in the HUD program) and the likely funds available for research put a premium on identification of priorities. The purpose of this paper, then, is not to come up with another laundry list of potential research projects but, rather, to look at the broad issues, i.e., the role of transit in our present and future society, with an attempt to identify places where research might aid transit in fulfilling its role.

GOALS FOR IMPROVED TRANSIT

There is little doubt that there is a significantly increased interest in improved transit in our cities. Whereas only a few years ago one could barely gain any serious consideration of improved transit in a comprehensive transportation program, today the problem in transit planning is often one of keeping expectations of citizens and officials within realistic bounds. This increased transit interest is occurring simultaneously with, and as a direct result of, an increasing interest in conservation of what is good in our urban environment and improvement of what is bad. Not only planners but citizens' groups and public officials are expressing more concerns about subjects such as air pollution, noise pollution, urban design, preservation of open space, improving opportunities for the disadvantaged, and reducing conflicts between automobiles and other human activity.

A number of metropolitan areas have developed lists of community or regional goals in recent years. An examination of these goals also amplifies the environmental concerns of the citizenry. By screening such goal lists, one can identify those that relate to transit improvement and from this compose another list that might be called transit improvement goals. The resulting list correlates well with the arguments one hears from advocates of transit in various cities. The major goals for transit improvements that were developed as an outgrowth of examination of community goals are as follows:

1. Improve peak-hour mobility;
2. Reduce the requirements for additional freeways in existing urban development;
3. Contribute toward a viable solution to the long-range transportation problem;
4. Provide for expanded mobility for non-car users;

Paper sponsored by Department of Urban Transportation Planning and Department of Economics, Finance and Administration and presented at the 49th Annual Meeting.

5. Reduce environmental nuisances (air pollution, noise, and pedestrian conflicts);
6. Encourage desirable regional growth patterns;
7. Allow more design flexibility for high-activity centers; and
8. Reduce transportation system costs.

The list is not exhaustive, i.e., others could find other items that might be added. Nor do all of the goals listed apply to all cities.

Nevertheless, it is believed that the list sets forth the major items where one can conceive of transit having a role in contributing toward improvement. It is perhaps noteworthy that most of the goals listed are not purely economic concerns. Social and environmental factors seem to dominate.

If transit is expected to make a contribution toward achievement of the goals listed, then one approach to the problem of transit research priorities is to examine the extent to which transit can fulfill these expectations or where it may be deficient. Exploration of deficiencies may point a direction for emphasis in research.

To help clarify some of the discussion that will follow, it is necessary to describe each of the goals listed.

Improve Peak-Hour Mobility

The frustrations of getting to and from work during peak traffic hours is one of the less savory elements of our modern environment. Although most of our urban transportation systems have sufficient capacity on a daily basis to accommodate travel demands in a reasonably satisfactory manner, during peak periods the situation is quite different. Peak-hour travel is costly in terms of time, operating expenses, and costs of moving goods in commercial vehicles. Traffic instability during these periods reduces transport reliability and safety and adds appreciably to the frustrations of modern man.

Improved transit can help to improve peak-hour travel conditions in 2 ways: (a) by improving travel speeds for transit users; and (b) by allowing faster speeds on certain roads as a result of diversion of automobile drivers to transit use.

Reduce the Requirements for Additional Freeways in Existing Urban Development

There is little doubt that expansion of the urban highway system is required and will continue. Yet there is an increasing amount of opposition to the construction of additional freeways, particularly through parks and highly developed areas in and near the central cities. One of the justifications given for express transit is its potential for reducing the need for some of the most controversial highways thereby helping to reduce the displacement of homes and businesses, the disruption of established living patterns, the taking of public parklands and other open space for highway construction, the taking of large amounts of land off the tax rolls, and the incidence of unacceptable aesthetics associated with some freeway development.

It is not proper to view improved transit as a potential substitute for all new road construction. Transit has limitations in performance that preclude such a substitution. However, given favorable travel patterns, express transit can often serve as a substitute and can usually be introduced with a less disruptive influence on the urban fabric. Therefore, if improved transit can reduce or altogether eliminate the need for the construction of some of the more controversial highways, or even defer their construction, a community benefit will have been achieved.

Contribute Toward a Viable Solution to the Long-Range Transportation Problem

There are strong indications that a number of our major cities will experience more difficult transportation problems in the early twenty-first century than they have so far known. Forecasts of travel demand in and near the centers of our larger cities are large compared to the availability of foreseen capacity of roads. Present and foreseen technological and political realities argue against a clear-cut solution to the highway

congestion problem in the long run. One of the goals for improved transit would be to make a contribution to the alleviation of this problem.

Provide for Expanded Mobility for Non-Car Users

There is a tendency to assume that virtually everyone has, or in the future will have, access to an automobile. However, for many this is not the case, and projections in several cities indicate that there will continue to be large numbers of persons who cannot use automobiles and who need inexpensive and reliable transportation to jobs and other activities throughout the metropolitan area. Persons especially affected by the lack of an alternative to the automobile include the poor—both the low income workers and the unemployed—the second worker in the one-car household, the elderly who cannot or choose not to drive, the young who are legally or financially barred from driving, the handicapped, and those who simply prefer not to drive. Still other groups could be identified including those desiring travel to school, amusement, medical, or other facilities in families where the one car is being used by the family breadwinner.

The goal of providing improved transportation to the non-car user is receiving more sympathetic attention at the same time that its solution is becoming less clear. This particular goal seems to have universal appeal in all our cities both small and large.

Reduce Environmental Nuisances (Air Pollution, Noise, and Pedestrian Conflicts)

The growing concern for the preservation of the quality of life in an urban environment encompasses a realization that nuisances such as air pollution, noise, and pedestrian conflicts are incompatible with many human activities. High traffic volumes moving through local streets that were not designed for such use often produce undesirable effects. More and more new developments are being designed so that heavy vehicular traffic can be sufficiently separated from pedestrian movement and other human activity so that an environment of high quality can be maintained. In and near the centers of large cities, however, the rigidity of present designs and the present and projected volumes of highway traffic are such that a reduction in highway travel in these areas would be desirable if it could be accomplished without arbitrary restrictions such as prohibiting vehicle circulation. Such reductions in street use would result in reductions in environmental nuisances including air pollution, noise, and pedestrian conflicts.

Encourage Desirable Regional Growth Patterns

The need for shaping regional growth has been forcefully put in metropolitan goal statements prepared in a number of cities. Land use should be properly arranged at the metropolitan scale for reasons analogous to why rooms in a building need to be properly planned. The reasons ultimately lie in providing more convenience, more opportunity, and a wider range of potential experience for the residents of the area. The desirability of larger, more intensely developed central business districts and the development of outlying high-activity, diversified centers providing an orderly mix of commercial, cultural, governmental, and educational activities in close proximity to high-intensity residential development have been established as goals in many communities. Factors in influencing this shaping have also been identified including the provision of improved transit service.

Allow More Design Flexibility for High-Activity Centers

Our increasing urban population is requiring ever larger high-density development, including regional shopping centers, airports, new towns, office complexes, and universities. Often these developments are of such scale that walking distance between major elements within them becomes excessive. Relatively low-speed, people-mover systems incorporated into design concepts allow architects and designers new opportunities for improving the appearance and function of such centers. The availability, reliability, and performance of such systems can be the decisive influence on the viability of such developments.

Reduce Transportation System Costs

The direct costs of providing for urban transportation are very large with some estimates suggesting that upwards of 10 percent of our personal income is being channeled into such use. Concern for the possibilities of reducing these costs, if only fractionally, is justified because such reductions could allow these funds to be used in other needed fields. If transit can make a contribution toward reduction of urban transportation costs, then it will have made a contribution toward achievement of this goal.

NEEDED TRANSIT IMPROVEMENTS

Transit improvements available to today's cities are limited by our knowledge of its impact, by performance of its hardware, by high costs and limited financial resources, and by the institutional environment within which improvements must be made. If the aggregate of these constraints are not severe, then transit can be expected to meet most of the goals listed, and funds for additional research, although desirable, only need to be nominal. If on the other hand transit meets expectations only in a limited fashion, the identification of these deficiencies should point the way toward promising avenues of transit research.

A more lengthy paper should review each goal listed, measuring and describing the extent of goal achievement and identifying transit deficiencies that must be overcome with future research. However, a thorough discussion of each goal is not possible in a brief paper because any one of the goals is a subject worthy of a book-length report. Instead, this paper will move directly to specific deficiencies of existing transit knowledge or technology, presenting bits of evidence that tend to support contentions and appealing to the goals as the basis for the discussion.

The Need for a Variety of New People-Mover Systems

Goal 7 expresses the need for new people-mover systems that will allow an increased design flexibility and more opportunities for improvement of our urban environment. These people-mover systems should be designed for low speeds (5 to 15 mph) to serve short trip lengths (0.25 to 1.5 miles), provide very frequent service, be completely automated, use small vehicles so that they may fit easily into an urban complex, and be extremely quiet so as not to disturb the urban environment. The opportunity for use of such systems is particularly obvious in large complexes under development or under control of single developers or agencies whether they be airports, universities, or new shopping centers. They all need horizontal elevators for the same reasons that vertical elevators are needed. These people-mover systems can also be used to expand the utility of conventional rapid transit by expanding the number of urban activities within easy access of rapid transit stations.

A number of such systems have reached advanced engineering stages, and it is reasonable to expect that they could be implemented and thus reliably serve the rigorous demands of urban transportation service. Included in these is the Westinghouse VDS system, the Dashaveyor, and the Carveyor. It appears that some of these will actually be built at least for shuttle service at some airports in the near future.

Yet developers or government agencies desiring such a system are faced with a variety of unknowns that in the aggregate tend to raise risks to excessively high levels. The result is that, although there is much discussion of the use of people movers, there is relatively little actual incorporation of them into new designs. These risks would be reduced with research, development, and demonstration programs that would push a variety of these systems to the operational stage. Included in the unknowns presently are the following:

1. No one can be sure of the reliability of any given system because none of the systems is actually in operation in daily passenger-carrying use. The reliability, safety, maintenance cost, downtime, and other factors are really unknowns. If any of these factors turned out to be negative in practice, it could invalidate the entire system and thus the design within which it is to be incorporated. These risks are usually too high for managers of large developments to face.

2. No one can be sure of costs because no systems have been built. Construction, operation, and maintenance of vehicles and ways and structures are simply unknown.

3. There is also the problem of proprietary systems. The conventional way for a public agency to develop a large public work is to write specifications that are suitable for obtaining bids from a large number of contractors and to accept the lowest bid. However, because most of the people-mover systems are proprietary, one cannot easily write the specifications without at the same time making a system selection on a basis other than costs. This means that complex evaluations of reliability and costs of complex hardware must be made by the local agency very early in the planning process. Although the Defense Department, the Atomic Energy Commission, or NASA have personnel and facilities to make such sophisticated evaluations, local public agencies simply are not so equipped. As a result, it is very difficult for such agencies to move ahead in development of such systems. This is an institutional constraint that is retarding transportation progress. Legal and administrative mechanisms need to be searched out that will help relieve this problem for local agencies.

The Need for Better Service at Lower Cost for Local Bus Systems

Goal 4 refers to the need to improve mobility for non-car users. This appears to be the fundamental and overriding goal and role for transit in medium and smaller cities in the United States. Densities are sufficiently low and activities sufficiently dispersed in these cities that from a capacity standpoint automobiles appear to be able to handle projected loads for the foreseeable future. There is nevertheless anywhere from 5 to 20 percent of the households in these areas that do not have access to a car; and as the majority of the population becomes more automobile oriented, the relative mobility of the minority becomes poorer.

Yet at the same time that our awareness of the necessity of maintaining public transportation for the minority is becoming sharper, the viability of local transit systems as self-sustaining businesses is being increasingly called into question. City after city is today faced with the take-over of systems that can no longer produce a reasonable return to stockholders; and as these take-overs occur, local governments are faced with a number of problems. Costs are rapidly escalating, but our concern for lower income persons makes it increasingly difficult to raise fares. Some of the major questions facing local administrators today include the following:

1. What is the public stake in keeping local transit moving? It is evident that to keep local systems operating will require subsidies taken ultimately from public taxes. But how much subsidy is justified? At a time when local governments are faced with an ever-increasing demand for their limited resources, how much can reasonably be put to subsidizing local transportation? At the national level, we spend billions on welfare, poverty payments, and employee training for unemployed or underemployed workers. To what extent would a fraction of that applied to local transit do more in achieving employment goals than would the same dollars applied in other projects? In Tampa, Florida, for example, it was found that the local contribution to national poverty programs was two times greater than the total cost of operating the local transit system. Yet the local transit system had been deteriorating and will continue to deteriorate unless external funds are applied. Could a few dollars now spent on other poverty programs be more wisely spent in improving the local transit system? These questions will not go away. It appears as though the problems described are just beginning. In-depth, detailed research is justified in helping local governments provide answers to these questions.

2. How can service be improved at a reasonable cost? After the obvious improvements of new buses, reliable operation, and reasonable frequency of service (considering usage) have been achieved, there is some doubt about the adequacy of service provided by local buses operating in streets in the standard mode. When densities are low and travel patterns diffuse, trip concentrations are so small that fixed route, fixed headway service is simply not to be had at a reasonable cost. This is the problem that will grow as our cities continue to develop in a dispersed pattern.

New concepts of operation and new equipment that will help serve in these situations must be developed. The dial-a-bus concept has potential for supplying answers. Hardware and software demands include a communications network between the central dispatcher and individual vehicles, and an automated variable route algorithm. Most needed in the near future is a demonstration of the concept using manual dispatching methods to learn more of its potential even prior to developing all of the required hardware.

There is also a real need to test, through demonstration, the validity of many recommendations concerning the use of exclusive bus lanes, particularly on freeways. For at least 10 years we as technicians have been recommending the use of exclusive bus lanes on freeways as an answer to rapid transit problems for medium and small cities. The idea conceptually has much merit. Yet at this moment there are no such exclusive lanes in operation on any of our freeways. If the idea has merit, we should try it out in a series of demonstrations to determine its costs and effectiveness. If it does not have merit we ought to dispense with its use as a bromide when we can think of no other alternatives.

A variation of this concept also needs demonstration. This variation involves the use of metered freeways with exclusive on- and off-ramps for buses. Metering will ensure that the freeway will always operate at high service level. The exclusive ramps ensure that the buses will have access to the freeway. The combination ensures that transit would have high-speed trips from outlying areas to downtown. However, there are a host of institutional and technical barriers to the concept that need to be worked out and tried in demonstrations. The cost-saving potential of such schemes is enormous when compared to the small investment required to try it out.

3. How can costs be cut? Because 60 to 80 percent of local bus operation costs are related to operators' wages and fringe benefits, it seems unlikely that much can be done about reducing costs of operation. Yet even though savings may only be marginal, because the problem is so great, work should continue on it. One idea that could make some improvement and would cost relatively little would include a management information system package for local bus operators. Such a management information system would include automatic passenger load counts, reliability checks, tabulations of various service indexes by line, line revenue and cost calculations, inputs to schedule development, run cutting, and manpower scheduling.

The Need for Better Rapid Transit Performance

Transit's ability to achieve many of the goals are directly related to its ability to compete with automobiles for a share of the urban travel market. Transit's ability to reduce requirements for additional freeways or to contribute toward solution of the long-range transportation problem is directly related to its ability to attract patronage. Similarly, its impact on goal 5, reducing environmental nuisances, will be only marginal if it cannot attract people from their automobiles, nor will it be able to reduce transportation system costs (goal 8) if it has few riders. In fact, every goal, with the possible exception of goal 7, can only be fully achieved if transit has sufficient performance to attract users in large quantities. The need for improved transit performance is particularly severe in our larger cities where most of the environmental concerns as expressed in the goals are most intense. Local bus systems operating on streets mixed with other traffic simply fail to provide service adequate to attract a large number of automobile users. Systems operating on their own rights-of-way where high speeds can be attained for a major portion of each trip are necessary to provide required service.

It should be noted that the capacity of our present hardware and systems is certainly adequate to achieve some goals. Rail systems have demonstrated capacities of 30,000 to 40,000 passengers per hour in one direction on one track as compared to 12,000 passengers per hour in one direction on an 8-lane freeway. Unfortunately, this does not indicate that one rapid transit line can be substituted for three highways. The issue is not whether the capacity is adequate, but whether the service is sufficient to attract a large number of automobile users.

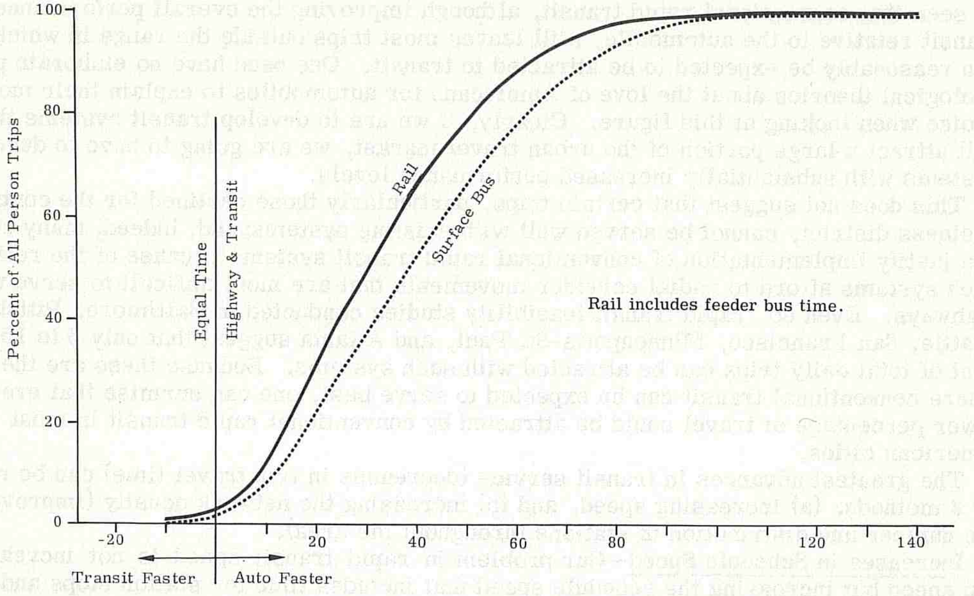

Figure 1. Comparison of travel times for rail transit, local bus, and highways in the Atlanta area, 1983.

Figures 1 and 2 show the relative travel time for local bus transit, a conventional rail-bus rapid transit system, and the highway system (under conditions of moderate congestion) for Atlanta, Georgia, in 1983. The relatively poor showing of the local bus system for most intraurban trips is vividly demonstrated by this graphic. It can also

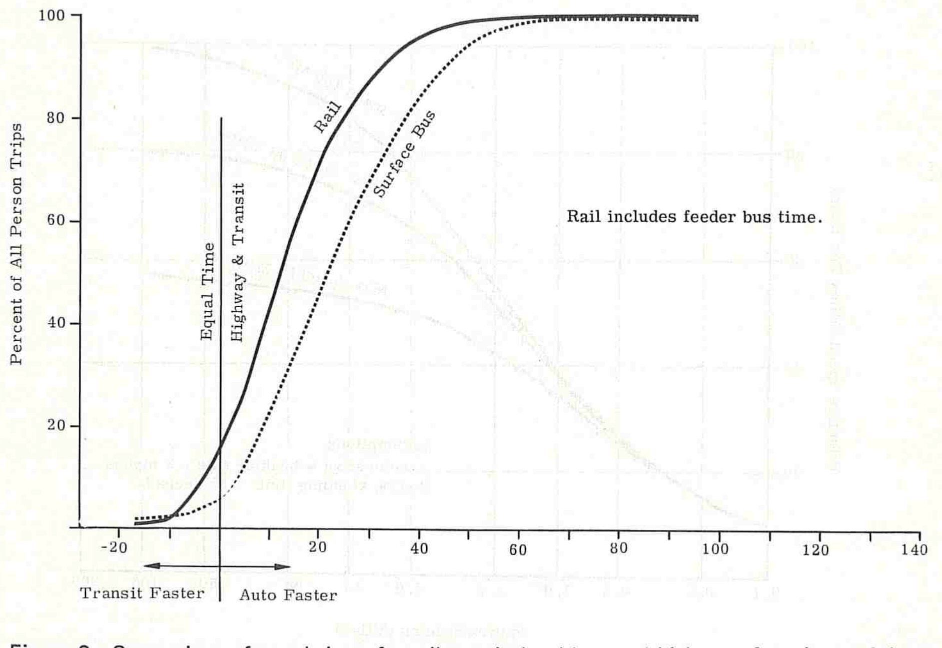

Figure 2. Comparison of travel times for rail transit, local bus, and highways for trips to Atlanta CBD, 1983.

be seen that conventional rapid transit, although improving the overall performance of transit relative to the automobile, still leaves most trips outside the range in which they can reasonably be expected to be attracted to transit. One need have no elaborate psychological theories about the love of Americans for automobiles to explain their modal choice when looking at this figure. Clearly, if we are to develop transit systems that will attract a large portion of the urban travel market, we are going to have to develop systems with substantially increased performance levels.

This does not suggest that certain trips, particularly those destined for the central business district, cannot be served well with existing systems; and, indeed, many cities can justify implementation of conventional rapid transit systems because of the relief such systems afford to radial corridor movements that are most difficult to serve with highways. Even so, rapid transit feasibility studies conducted in Baltimore, Pittsburgh, Seattle, San Francisco, Minneapolis-St. Paul, and Atlanta suggest that only 5 to 15 percent of total daily trips can be attracted with such systems. Because these are the cities where conventional transit can be expected to serve best, one can surmise that even a lower percentage of travel could be attracted by conventional rapid transit in most American cities.

The greatest advances in transit service (decreases in trip travel time) can be made by 2 methods: (a) increasing speed, and (b) increasing the network density (improving the number and distribution of stations throughout the area).

Increases in Schedule Speed—Our problem in rapid transit speed is not increasing top speed but increasing the schedule speed that includes time for station stops and acceleration and deceleration for stops. The top speed is now in the 70- to 80-mph category with rapid transit, but the schedule speeds including stops decreases this to 30 to 40 mph. This relationship is shown in Figure 3. We can increase schedule speeds by increasing station spacing, but at the same time increasing station spacing reduces access of patrons to the system and increases feeder travel. Our need is to both increase speed and increase accessibility of the system.

There seem to be 2 concepts available that have potential for improving system performance. One of these is the gravity vacuum-tube concept that provides for higher schedule speeds because of higher acceleration and deceleration potential, which results

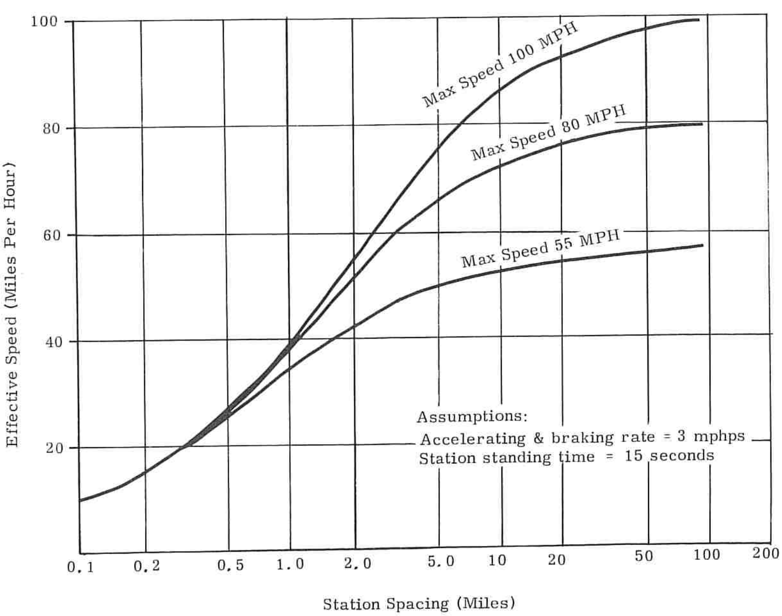

Figure 3. Effective speed versus station spacing.

from acceleration taking place while vehicles are moving downhill and deceleration occurring while they are moving uphill. This enlistment of gravity to help with starts and stops of the system allows increases in schedule speeds according to its backers by some 15 to 25 percent. It would appear that this concept has more application for longer distance travel than typical intraurban trips. Nevertheless, the possibilities of its improving the performance of urban systems should not be overlooked.

The second concept for improving system speeds is the small vehicle, origin-destination "personal" rapid transit. This concept involves small vehicles fully automated that move from the station of origin directly to the station of destination without intermediate stops. Thus, schedule speeds could conceivably be 60 to 70 mph or more, a substantial increase over conventional systems. This concept was explored in the recent HUD research studies, and several major problems are already evident.

1. Occupancy for each vehicle would necessarily be low because the number of persons moving from any one point in a city to any other single point in a short interval of time is small; thus increasing the vehicle size will be of no help in increasing the capacity of the system. One estimate made for Minneapolis-St. Paul suggested that an average occupancy of 1.3 or less is all that could be expected during peak traffic hours (1).

2. Because of low vehicle occupancy, headways between vehicles would necessarily have to be very small in order to get a reasonable line capacity. Vehicle headways of one second or less will be required to even get close to required capacity. The command and control and other hardware requirements required for merging and demerging and fail-safe operation at less than one second headways present problems of great magnitude. The only solution suggested in the HUD studies was adding parallel links on sections of high volume. However, the additional links further complicate the switching and control problems as well as the problems of costs and imposition of such system on the existing environment.

3. Interchanges required for high-speed operation between lines of personal rapid transit would require large land areas and would not be dissimilar to highway interchanges in this respect. Thus, the achievement of some of the goals desired for improved transit would be reduced. Similarly, stations would necessarily be large because of the requirement for bypass tracks, storage tracks, and acceleration ramps for vehicles. Because stations must be placed in the centers of the most intensely developed areas of our cities, they would be quite difficult to build in an elevated configuration and very costly to build underground.

Thus new systems, even if they can be developed, will have their share of problems; but because of the real need for better system performance, research should continue.

Increasing Transit Network Density—Another way to improve the service of rapid transit in addition to increasing its speed is to provide increased network density that will allow more stations better distributed throughout the area. Most rapid transit proposals in our cities consist of 50 to 100 miles of separate right-of-way, grade-separated facilities knit together with feeder buses operating at 10 to 15 mph. Such a system is supposed to compete with a road network consisting of thousands of miles of system that provide for almost direct service from anywhere to anywhere for those with cars (and this is tending to include most persons). A denser transit network could, of course, be justified if more people were carried (the cost per ride would still be okay even though total costs were up). The real limitations in increasing network density is the need to keep costs within reasonable limits. In addition to savings that might be brought about by improved hardware, better ways of using elevated structures, which can be built at one-half to one-fourth of subway construction, should be employed. Better administrative, legal, and financial mechanisms are needed for carrying out elevated structures in dense areas. By combining buildings, roads, streets, open space, and other urban elements properly, a designer can plan acceptable elevated structures for dense areas. However, our mechanisms for carrying out air-rights construction, running rapid transit through the middle of buildings, putting commercial facilities underneath elevated structures—all become very difficult when implementation requires simultaneous decision and financing on the part of a variety of urban developers, officials, and citizens.

Lowering the cost of subways and tunneling would also be a real boon to development of transit. Cleveland was able to build its surface rapid transit system even though it carries relatively few riders, as a result of having and using inexpensive rights-of-way. Reduced costs of tunneling would present such opportunities to other communities that do not have such natural assets as easy rights-of-way.

The ability to reserve rights-of-way for future use of transit construction would also enhance the possibilities and reduce the disruption and costs associated with development of rapid transit. Reservations of a narrow strip of radial right-of-way for transit use in each major radial urban corridor would seem appropriate in many instances. These radially oriented corridors are the ones where highway congestion will be most acute in future years; and, regardless of whether future rapid transit be conventional or "new concept," it seems most likely that these radially oriented rights-of-way will be useful. More needs to be known, however, on administrative mechanisms and financing for such rights-of-way.

Lowering Transportation System Costs

As suggested earlier, if transit could make even a small contribution to the reduction of overall urban transportation cost, a real benefit will have been achieved. Average costs of travel by automobile appear to be about 9 cents per passenger mile. However, if automobile financing costs and the additional costs (above average cost) associated with highway construction, vehicle operation, insurance, and safety are included for areas in and near large cities, then automobile travel could well exceed 15 cents per passenger mile. Local bus transit costs about 8 to 10 cents per passenger mile, and rail-bus systems recently proposed in a number of large cities appear to cost 10 to 15 cents per passenger mile. However, costs exceeding 15 cents per passenger mile occur when attempts are made to develop rapid transit in low-density cities without large central business districts and without availability of cheap rights-of-way for transit construction. Thus there is a real need to find ways to reduce costs for medium- and low-volume systems. There are several ways that should be explored to help to achieve this goal.

1. New systems with higher performance discussed earlier could lower costs per passenger mile because of increased utilization of the system. Additional passengers tend to increase operating costs, but tend to reduce the cost per passenger for fixed rights-of-way and structures.
2. Use of buses on separate busways appears to have some cost advantages for low-volume operation.
3. As noted earlier, reduced cost for tunneling, more use of elevated structures, and a system of right-of-way reservations would tend to reduce cost to more acceptable limits.

Need for Better Knowledge of Potentials for Use of Bus Rapid Transit

The use of buses on separate rights-of-way has been discussed for years; its potential advantages are well known, including the possibilities of feeder-trunk service, better tailoring of service to reduce the number of empty seat-miles, and reduced capital costs resulting from no requirements for signal systems or power distribution. Thus the goals listed earlier relating to improved performance or reduced cost conceivably have some potential for better achievement through use of buses in smaller cities.

However, no one has yet put a separate busway into operation. Part of the reason for this is that the risks associated with an unknown operation are too high and need to be reduced through research. Included in such questions are the following:

1. More information is needed on the use of buses in tunnels; the dimensions of tunnel sections for busways, particularly in stations, need to be better known. The requirements for ventilation and the cost for tunnel ventilation need to be better known. The safety and capacity of buses operating through multiple platform stations particularly in underground areas need more research. Work needs to be done on the potential

for modifying buses so they could operate for short distances in tunnels without internal combustion engines in operation.

2. Additional work on vehicle design that would provide larger vehicles for use on separate busways needs to be explored. If buses were operated only on separate rights-of-way, the dimensional constraints could be released allowing longer and wider buses. This would allow better manpower utilization (one of the real problems with bus operation, particularly with high volumes) as well as allowing designers to provide vehicles that might be more acceptable to the public.

3. Standards for busway construction including width of running surface, shoulders, median barriers, turnarounds, and other features need to be better understood.

Perhaps the most important thing would be to get a busway actually into operation so that a demonstration of many of these concepts could be put to the test.

Need for Better Knowledge of Relationship Between Transit and Regional Growth Patterns

Goal 6 refers to the desire expressed by many areas for structuring of regional growth. The objectives are to provide a better urban environment and to meet social objectives by the clustering of urban development into nodes of diversified high-activity centers providing a mix of commercial, educational, office, governmental, and residential use in a setting of good urban design. Assuming that this land use concept is desirable, the question remains, Will transit help bring it about? Forgetting for the moment the improved design and mixed land uses, will transit even bring about higher densities in clusters of high density around stations? The answer to this at the moment appears to be sometimes "yes" and sometimes "no." Transit trade associations can produce large volumes of testimony on the impact of transit on structuring of land use, but examination of this material reveals more rhetoric than fact. It seems quite clear that clustering has taken place in Toronto and is going on in San Francisco even in advance of transit construction. However, relatively little such development has occurred in association with the Cleveland system. Hans Blumenfeld, who is perhaps the most respected of urbanologists who have examined this question, says of Canadian cities: "Given the fairly general availability of the private automobile and of good all-weather roads in Canadian urban areas, the presence of rapid transit or commuter railroad lines may lead to some concentrations around the stations, but will not by itself substantially change this pattern of 'spread city.' This can only be done by fairly strong controls of land use and of utility location."

It appears there are times and conditions when transit can have an impact and others when it has relatively little impact. Research needs to be conducted that will help confirm the conditions that are required to bring about desirable urban land use development goals.

SUMMARY

This paper has identified a set of urban goals that are often implicitly (or explicitly) the basis for desire for transit improvements in U.S. cities. The extent to which contemporary transit technology and knowledge can achieve these goals is in question. Transit often fails to achieve goals because of lack of knowledge of its impact, limitation on performance of transit hardware, its high costs, and the institutional environment within which it operates. New knowledge, hardware, and techniques are all needed.

Some specific needs were identified as follows:

1. A variety of new short-distance, low-speed people-mover systems,
2. Better service and lower costs for bus systems,
3. New hardware to provide improved performance for rapid transit,
4. More knowledge and experience on bus rapid transit, and
5. More knowledge on impact of transit on land use.

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Mass Transportation: Future Research Needs

GEORGE F. GOEHLER, Southern California Rapid Transit District

•I HAVE LONG FELT that research is much needed in the public transportation field. Too long we have made exclusive social and political commitment to the private automobile, somewhat on the logic that the automobile would solve all of our transportation problems. During this period, the economic ability to undertake research has been nonexistent for public transportation agencies. However, we have been doing our job, day in and day out, in every major city in America. You might say that public transportation was the dying industry that would not die.

Now there is a realization at the federal level, from state governments, and local jurisdictions that the automobile, while solving many problems, causes others, the kinds of problems that public transportation can solve. So at long last, financial capabilities may soon be available to public transportation.

To many, the term research applied to public transportation elicits thoughts of exotic investigation into new systems or queries devoted to obscure subject matter. But, as one who has spent most of his life on the practical side of providing transportation—the front line of the industry—it means practical application of existing and new information.

We are proud of ourselves in Los Angeles, because over the past years we have taken existing materials and instituted new concepts. So today, I would first like to share with you some of these new concepts and approaches, and second suggest research into some practical, everyday matters that would be of great assistance to the practitioner.

Los Angeles is famous for its freeway system. One of our early innovations in service was the development of what we call the Freeway Flyer. Our first Freeway Flyer line operated between the western San Fernando Valley into downtown Los Angeles. It was established in mid-1958. Initially, we had 260 passengers a day on 4 inbound and outbound trips. Now more than 3, 200 commuters ride the line on 65 inbound and outbound trips.

From that one Freeway Flyer we grew to 30 lines on 8 freeways. No provision is made at the outer terminals for automobile parking, yet studies show that a number of our Flyer passengers drive to a point along the line and park on city streets. We have succeeded here in providing a service that has attracted passengers from the private automobile.

Development of the freeway system also found us in the age of the computer. Our day-to-day bus operations are directly linked by the use of electronic data processing for scheduling. This was a field in which the Southern California Rapid Transit District pioneered. Using an IBM 1401, we compute basic bus schedules; produce the sheets—which we call paddles—from which our drivers receive their bus runs; and develop supervision and information schedules, work-run assignments, and accounting and all related data. Electronic data processing enables us to analyze traffic and passenger flow for immediate and long-range planning.

Like other urban areas, we find that minority community problems revolve to a great extent on availability of adequate public transportation. The Southern California Rapid Transit District was part of a study by the State of California using funds provided by the U.S. Department of Housing and Urban Development to operate a Transportation and Employment Project. In March 1969, the project ended. Since that time, the

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Paper sponsored by Department of Urban Transportation Planning and Department of Economics, Finance and Administration and presented at the 49th Annual Meeting.

Transit District has maintained continuous service on the experimental Line 100 and makes diversion payments of $500 monthly to a private operator. This line links the Watts area to commercial, medical, and industrial facilities in South Gate to the east and to Los Angeles International Airport on the west. Keeping this line was primarily recognition of the social and economic benefits it brought to the community.

Another community-oriented line is the new service instituted from the Watts area, and adjoining communities, to handle weekday rush hours. This line has reduced traveling time for minority persons having employment in westside Los Angeles. Commuters on that service save as much as an hour and a half in travel time over previous service. This trip, partly by freeway, services Beverly Hills, West Los Angeles, Pacific Palisades, and the UCLA campus.

Almost any gathering of residents in Los Angeles will result in a discussion of smog. It is a problem in the Los Angeles basin that some say is of serious proportions. All large metropolitan areas are plagued with this problem in varying degrees. We have consistently made an effort to reduce objectionable emissions through preventive maintenance and the use of highly refined diesel fuel. It has been found by the Air Pollution Control District that RTD buses might be responsible for as little as $^{4}/_{10,000}$ of the air pollution caused by all motor vehicles in Los Angeles County. Everyone agrees that the automobile is the greatest contributor to air pollution. It is estimated that about 85 percent of the pollution in the Los Angeles basin is a result of the automobile. A single bus will carry a number of persons equivalent to 40 automobiles. So to the extent that we can improve our service and attract new riders, we also reduce air pollution.

Getting new passengers requires a comprehensive advertising, marketing, and community relations program. We are pleased to have a highly professional program, with a record of success—a record gained through the combined efforts of our advertising and marketing staff and top performance by transportation and maintenance personnel. The value of marketing public transportation in our area becomes obvious when you consider the fact that 51.8 percent of Los Angeles County households have only one automobile and 16.7 percent have no automobile at all. Accordingly, a major aspect of our advertising and marketing activity promotes the ExtraCar. The logic of this is that if the family car is in use take the ExtraCar—the bus. A look at our recent record shows that our efforts are paying dividends. In 1969, according to recent checks, riding is up 1.4 percent; nationwide there has been a decrease of 5.6 percent.

To complement our advertising effort, we have a complete program of community relations that includes activities with business and government. We maintain regular contact with the staffs and elected officials of the cities we serve Our employees participate as active members in over 50 chambers of commerce. We call these employees Ambassadors. They live up to their name by demonstrating that RTD is interested in communicating at the local level. This activity pays us dividends, as was evidenced by the cooperation the chambers gave us when we recently inaugurated Exact Fare. Chambers distributed pamphlets on Exact Fare, ran articles in their publications, and encouraged numerous member businesses and corporations to do the same.

Coordination with traffic engineers and highway departments throughout the Transit Districts's service area is a must. Most recently in the city of Los Angeles, we formed a Joint Traffic Flow Improvement Team. The Team is studying improvements in signal timing, bus stop relocations, exclusive curb lanes, curb bays for buses, and improved turning at intersections.

One of our most heavily traveled thoroughfares, Olympic Boulevard, stretches for 15 miles from the ocean at Santa Monica through West Los Angeles to downtown Los Angeles. The city of Los Angeles and the Transit District are now experimenting with changing bus stops from nearside to farside on this Boulevard. We plan to evaluate the effect of this on motor vehicle flow and operating schedules of our buses.

The most exciting transit proposal to come before the District in recent years is our proposal to the Urban Mass Transportation Administration for funding of an exclusive, grade-separated busway in the center of the San Bernardino Freeway. This will provide an exclusive express busway operating between the city of El Monte, in our eastern suburbs, and the city of Los Angeles. This $36 million project would utilize park-and-ride and kiss-and-ride facilities with special curb-lane operation once the

buses arrive in the central area. We hope to provide 6,000 seats an hour on the busway or the equivalent of almost 3 freeway lanes. With appropriate provision for disbursing the buses after exit from the 11-mile busway, we could double the 6,000 figure. We feel that the success of this project will lay the groundwork for other similar projects in Los Angeles and the United States, and provide momentum for further development of rail rapid transit.

These projects I have identified are practical applications of the existing knowledge. There is a myriad of items of an everyday variety that desperately needs attention. This may be the area of research that we should explore. Let me list a few.

1. Methods of relieving traffic congestion in the peaks—This includes the auto-transit interface and better facilities for changing modes. Needed is a park-and-ride or kiss-and-ride facility that truly encourages the automobile driver to leave his car for public transportation. This also includes the design of a passenger collection system for the suburbs that competes with the convenience of a private automobile, including a modified bus collection system such as dial-a-bus. This may possibly take the form of a passenger operated, but publicly owned, vehicle eliminating the need for the commuter to have a second car.

2. Improved traffic flow through the central business district and other delivery areas—Research in this field must develop techniques that most efficiently move people, not vehicles, in high-density areas. Furthermore, such research must have full cooperation and coordination from the entire community. We feel we are achieving this coordination in Los Angeles with our Joint Traffic Flow Improvement Team. Research should specifically study such items as perimeter parking areas, exclusive bus streets or lanes, bus-actuated traffic signals, special delivery bays, or off-street facilities, and even investigate some of the exotic transportation systems that require a change of mode.

3. Bus design—I believe that vehicle design can contribute more to the quality of service provided. Design should incorporate more convenient passenger ingress and egress with improved visibility, comfort, and aesthetic value. It should also have features that enable the transit operator to carry persons who depend solely on public transportation—the blind, aged, and handicapped. These features, however, should not interfere with general passenger usage.

4. Greater utilization of publicly dedicated rights-of-way to improve their people-carrying capacities—Our proposed exclusive busway in the freeway median is an example of this type of investigation. Research is needed on (a) the spacing of stops and the design of access ramps for such a facility, (b) reversible lanes with either mixed or exclusive bus operations, and (c) the metering of on-ramps to the freeway giving buses preferential treatment. This is vital to our operations.

5. A sophisticated analysis of who rides buses and why—Serious marketing studies are needed about public transit riders. Over the years, we have studied how many people ride and when and where they ride, but very little is known as to why they ride and what kinds of transit services will attract new passengers.

6. Compilation of accurate statistical data—New means of collecting passenger demand data are needed so that schedules can rapidly be adjusted to demand changes. Research in this field should include the development of accurate on and off checking devices, recorders, or electronic censors; more reliable origin and destination data collection techniques; real-time transmission of on-board data; and computerized headway control.

7. Vehicle location systems—In order to provide proper headway adjustments, a reliable vehicle location and data transmission system is needed. The Southern California Rapid Transit District has installed a data transmission system. We call this a second generation system that transmits the vehicle line number and run number automatically, at the initiation of a radio transmission. The Chicago Transit Authority is working on what might be called the third generation of this system in its installation of a vehicle locator system that will automatically interrogate the bus and feed data into a computer. More work needs to be done to increase the reliability of these systems and their ability to program the necessary service adjustments based on input.

8. Passenger information—We are urgently in need of a better way to tell potential passengers how, when, and where they can use public transportation services. One hundred years ago the passenger would ask a station agent for information and the agent would look it up in a complex schedule book to verbally inform the passenger. It is still done that way today! Public transportation is not being used to capacity, often because people do not know how they can avail themselves of the service. We are working on ways to computerize this information and make it available for instantaneous readout.

9. Fare collection system—There are some who feel that ultimately transportation will be a service available without the payment of a fare. I am afraid that this is a good many years away. In the meantime, we need reliable and secure means for collecting fares. New fare collection devices should collect the variety of fares that are based on length of rides. A fare box that will accept dollar bills would be a good start. Inflation has increased the number of dollar bills used on transit vehicles and, with the exact fare system now in effect on all major transportation operators, the inability to accept a dollar bill is inconvenient to our passengers. Further down the line is the need for fare collection devices that make change, accept passes, and issue and accept transfers. A prepayment card from which the value of your ride can be electronically deducted would be a vast improvement over our present monthly pass system.

10. Bus power plants—Although the bus is certainly a more efficient people-carrying device than the automobile, any propulsion system that adds to the problem of air pollution is certainly undesirable and presents a problem to which the forward-looking transit agency should direct its attention. There are a number of projects now under way directed toward improving bus power plants including the turbine engine, Stirling engine, steam-external combustion systems, natural gas internal combustion systems, and many varieties of electrical vehicles. Much more work is needed before the bus operators can make financial and operational commitments to these promising systems.

Here you have some of my thoughts as we approach what I know will be a new era in mass transit—an era marked by revitalization, innovation, and, I hope, imagination.

Marketing Urban Transit

LEWIS M. SCHNEIDER, Graduate School of Business Administration,
Harvard University

•IN THE RELATIVELY short amount of time I have to discuss the subject of marketing urban transit, I hope to accomplish 3 things.

1. Put forth the proposition in the strongest terms possible that the phrase "mass transit" is a misnomer. As a result, determining the objectives and investment strategies for transit systems is not an easy task. Marketing skills appear to be particularly important.
2. Raise some questions regarding the potential conflicts between economic rationalism, consumer sovereignty, and the realities of urban life.
3. Present 2 contrasting scenarios of what urban transit might become if current trends continue.

MASS TRANSPORTATION—AN INAPPROPRIATE TERM

The very words "mass transportation" have created much of the problems facing the transit industry, for "mass" implies a homogeneous demand that can be accommodated by a standardized product. Yet, we know that in every other aspect of urban life heterogeneity is the rule. The consumer is perfectly willing to spend 3, 4, and even 10 times as much money on a given functional product to achieve higher levels of performance, status, comfort, or appearance. Marketing managers are constantly sifting consumer data trying to delineate meaningful segments before matching product to customer.

Yet, what of the transit industry? It, for the most part, continues to offer relatively standardized boxes on steel or rubber wheels for all—rich and poor, worker and shopper, young and old.

The consumer is told: "If you don't have an automobile or want to use our service, you'll do so on our terms. Make your choice. Would you rather endure traffic jams on expressways, or suffer overcrowding in dirty, unsafe, uncomfortable stations or vehicles? Or, perhaps, you'd rather not make the trip?"

Interestingly enough, this last alternative many well be the ultimate solution to the transit problem. It seems clear that we must devote more of our energies to reducing the need for urban trips per se, rather than trying to accommodate them.

In this regard, it is interesting that the popular image of public transportation in Japan is the glamorous, fast, comfortable Tokaido Line. I keep remembering the photographs of the hired "pushers," whose job is to stuff the consumer into the unyielding commuter railroad cars. Is this really the urban world we want in the future?

THE MARKETING MATRIX

I find it useful to analyze the demand for urban transportation by constructing a simple matrix (Fig. 1). The rows represent classifications of consumers and the columns types or characteristics of trips.

The fundamental classification of consumers focuses on access to an automobile and trip-making status, namely,

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1. Those with access to an automobile and making trips,
2. Those without access to an automobile and making trips, and
3. Those without access to an automobile and not making trips.

Other row dimensions could include age, sex, income, and race. The columns describe trips in terms of

1. Purpose (work, shopping, social-recreation, school),
2. Origin-destination corridors, and
3. Time of day.

The complete matrix permits an analysis of the costs and benefits of particular strategies in quite detailed terms, for example, the investment and operating costs necessary to achieve a 70 percent share of the peak-hour work trips made by automobile-oriented travelers between a given suburb and the central business district (CBD). Note that this example implies a specific volume of peak-hour CBD work trips. In analyzing the matrix, one must question the total trips assigned to a cell as well as the distribution between modes; e.g., Do we want substantial increases in CBD-oriented trips? In this regard, a Wall Street Journal article (1) raises some important ecological questions regarding increases in the density of business and commercial activity in New York City's core.

The matrix also spotlights the heterogeneity of consumer demand for urban transportation. The automobile owners and users, of course, are the villains insofar as congestion, pollution, noise, and undesirable land use are concerned. If the environment is to be improved in the name of "balanced transportation," automobile traffic will have to be diverted to transit. In some instances this will be difficult, ironically because transit already has an overwhelming share of the market. Only about 10 percent of the peak-hour commuters to Manhattan arrive by automobile or taxi. In other cases, significant diversions may well be possible if the transit industry can really produce an automobile-competitive product.

Those without access to an automobile, but making trips, are truly captives of transit. They include the young, old, poor, and handicapped. Certainly they require transportation. The real question is: Should the transit product be the same as that designed to divert automobile drivers?

Instinctively one would say "no," for these diverse groups require different combinations of speed, price, convenience, and comfort. For example, in many cities one of the basic roles of the transit company is to provide service to school children. Unfortunately, in the morning the school and work trip peaks overlap. Vehicles are overcrowded with school children often riding at reduced rates of fare. Vandalism tends to be high, further adding to the discomfort of transit. A case could surely be made for operating completely separate school bus services, subsidized from the educational budget, allowing higher quality transit equipment to be used for regular automobile-oriented commuter traffic. In terms of systems analysis, the trade-off between size and location of schools and the scope of the school bus system seems most appropriate.

Finally, we must consider the needs of the immobile poor, those who make relatively few trips and have no access to an automobile. Gurin (2) has a penetrating discussion of the problems of this group. Recently we have witnessed a variety of subsidized

Classification of Consumers	Classification of Trips			
	Work	Shopping	School	Social-Recreation
Automobile available and making trip				
Automobile not available and making trip				
Automobile not available and not making trip				

Note: Other row dimensions might describe the consumer in terms of age, sex, race, income, or other characteristic.

Other column dimensions might classify trips in terms of origin-destination corridors and time of day.

Figure 1. The urban transportation marketing matrix.

bus services linking ghettos and suburban plants. Invariably, the cost per newly employed worker using the buses has been extremely high. Often the new workers purchase automobiles. The traditional transit product has been unable to keep the customer.

ECONOMIC RATIONALISM AND CONSUMER SOVEREIGNTY

At this point some economists say: "We can't afford the luxury of the private automobile. One rail line is the equivalent of 20 highway lanes. We must invest in high-capacity transit facilities and force the rider to use them. Without these facilities our urban areas are doomed."

Let me make 2 simple observations on this point. The first is that the consumer is not impressed with cost-benefit ratios, economic analyses, and the like when the resulting product is unsatisfactory.

But more critical is the fact that expensive investments in transit facilities, though important, are not the crucial determinants of urban form and economic health. Brooklyn and Harlem are well served by rapid transit lines, yet the blight and human misery continue unchecked.

Economic rationalism might well determine that the community's dollar should be allocated more to schools, subsidies for work training programs and industrial development, and housing than to transit. In a healthy urban economy, most of our transportation problems will be relatively easy to solve.

URBAN TRANSIT IN THE FUTURE

Where is the urban transit industry headed and what is the marketing challenge?

On the one hand, it is not unreasonable to predict that if present trends continue, our major cities will be served by monolithic metropolitan transportation systems, each generating substantial operating and capital deficits. In the name of coordinated metropolitan transportation, a sort of perverse conglomerate will emerge. Independent suburban bus companies and the remaining central city private transit operations will be purchased with public funds. Through an application of Gresham's Law, the most uneconomic labor practices and compensation schemes will remain as the efficient smaller companies are swallowed up by the giants.

These huge systems will be almost unmanageable. The morale of the management group will be low. Standards of service at best will be adequate. Poor maintenance will swallow up new capital, and a sense of complete bureaucratic frustration will prevail.

Is there no alternative? Let me outline some basic guidelines, which if implemented might well result in a healthier, more attractive transit industry.

1. All operating expenses must be met from user charges. The transit company must not be a subsidy mechanism or an agent of the welfare department. Direct subsidies should be included in a basic cost of living package for all citizens that enables them to exercise their consumer sovereignty and choose mass transit or the automobile for urban trips. An interesting analysis of providing automobiles to the poor at low cost has been prepared by Myers (3). Similarly, highway user charges should more adequately reflect the actual construction and maintenance costs of different segments of the road system taking into account direct social costs, e.g., housing relocation and preservation of open space.
2. Monolithic metropolitan transportation agencies providing a variety of line-haul and feeder services utilizing buses, commuter railroads, and rapid transit lines might well be split up into more manageable special purpose systems. Although one agency might offer area-wide line-haul services, individual communities would be responsible for designing and operating their own feeder routes. A case can be made for separate special-purpose line-haul systems as well. The independent Delaware River Port Authority has had success with its high-quality commuter rapid transit line between Lindenwold and Philadelphia. These independent feeder systems would feature flexibility and innovation in place of the current regulated rigidity. Jacobs (4) has discussed the virtues of innovation and flexibility in urban transportation. The technologies of

feeder operation would range from dial-a-buses through jitneys to traditional surface buses. Separate transportation systems would be designed for school children and possibly senior citizens, featuring specialized routes, equipment, and fares.

3. Where the density of line-haul traffic is unable to support expensive rail rapid transit routes, extensive use should be made of busways directly serving major traffic generators. Instead of moving on fixed routes on predetermined schedules, buses would wait at peak load points—in effect, an industrial school bus service (5). Then, utilizing separated rights-of-way wherever possible, they would provide a powerful alternative to the private automobile.

4. It is clear that independent feeder systems to area-wide line-haul rapid transit routes may still be unable to solve the problem of linking dispersed suburban residences to scattered suburban industrial plants. The individual suburban firms or groups of firms may well have to take the initiative in forming special purpose car pools or commuter bus services, if automobile congestion becomes severe.

5. Perhaps, most important, management must play a major role in transforming this traditional, conservative, production-oriented industry into a modern consumer-oriented service industry. Blurton in Peoria (6) and Bain in Reston (7) have demonstrated conclusively that technology in and of itself does not guarantee success. A determined management appears to be crucial in changing basic travel habits.

CONCLUSION

The prospect of new capital is not the transit industry's salvation, for capital can too easily be misallocated through investments in inappropriate facilities or dissipated by poor maintenance. The industry is still caught up in the vicious circle of declining productivity, high operating costs, poor service, increasing fares, and level or declining patronage. A radical approach is needed, It is hoped that new marketing-oriented transit strategies will provide the answer.

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Mass Transportation: The Hardware

MICHAEL G. FERRERI, Simpson and Curtin

•UNTIL RECENTLY, selection of hardware for mass transportation systems involved few alternates, with orders limited to General Motors standard buses or reorders of rapid transit cars currently in use. In recent years, however, a new interest in mass transportation for both intercity and urban application (stimulated by federal interest and funds) has been reflected by development of new vehicle systems that attempt to tailor the hardware to specific mobility requirements—a reversal of premise.

Growing traffic problems have caused more cities to look to mass transportation as a potential solution: This too has stimulated a search for mass transportation tools to match specific jobs. Medium-sized and even small cities are searching for "nonhighway" solutions to their transportation problems. Moreover, it is evident that the transportation consumer is demanding new facilities—highway or transit—that conform better to contemporary standards of comfort and convenience. In fact, continuing improvements in automobile and air travel make many of the traditional concepts of mass transportation painfully obsolete, even today.

The principal thrust of the current resurgence in mass transportation system development may be characterized by 3 basic divisions.

1. Sophistication of more or less conventional rail systems through automation and improved hardware design. A few recent examples of this development are the Bay Area Rapid Transit (BART) System (Fig. 1), which will use a new, wide-gage aluminum car designed for complete automotion; the Delaware River Port Authority Lindenwold line (Fig. 2), which is more conventional than BART, but uses air-conditioned, fully automated cars; and the recently opened Victoria line in London (Fig. 3), which utilizes conventional cars with aluminum skins and full automation.

2. Monorail and duorail rubber-tired systems that operate in trains in the conventional way but on modified track structures. The SAFEGE monorail (Fig. 4) has been successfully operated on a test track in France. The Westinghouse transit expressway (Fig. 5) is operated in Pittsburgh on a fully automated test track utilizing lightweight vehicles with many standard motorbus components.

3. Small vehicle computerized systems that range from amusement park monorail systems to exotic personalized transit concepts. The Minirail, used at Expo '67, operated successfully at a number of fairs, including the closed-car operation at the International Traffic Exhibition in Munich (Fig. 6). More radical departures include the nonstop Carveyor system (Fig. 7), which uses unpowered cars moving on a continuous conveyor belt, and computerized operations such as Starrcar and Teletrans.

Figure 1. Bay Area Rapid Transit District car, San Francisco.

Paper sponsored by Department of Urban Transportation Planning and Department of Economics, Finance and Administration and presented at the 49th Annual Meeting.

Figure 2. Delaware River Port Authority Lindenwold high-speed line, Philadelphia—New Jersey.

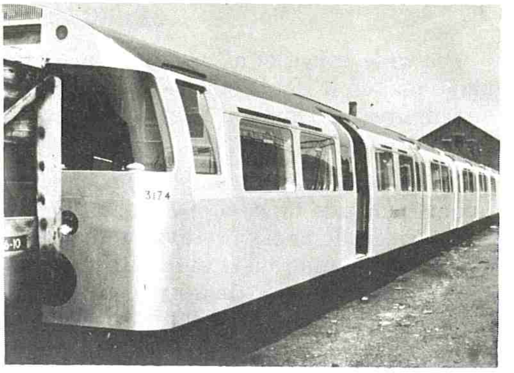

Figure 3. Victoria line, London, England.

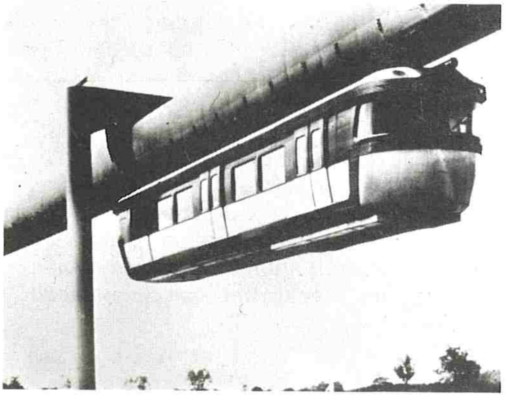

Figure 4. SAFEGE monorail, French test track.

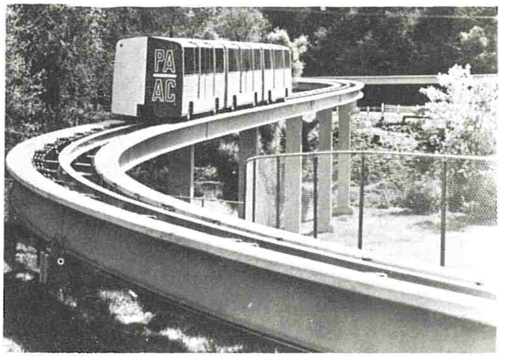

Figure 5. Westinghouse transit expressway, Pittsburgh.

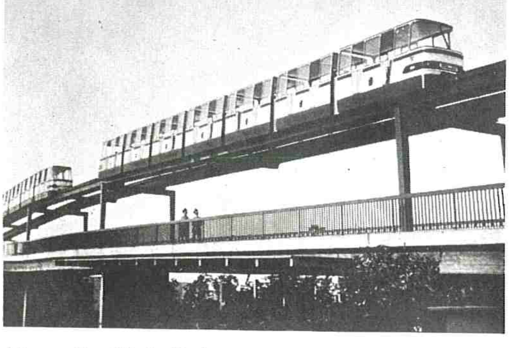

Figure 6. Minirail, International Traffic Exhibition, Munich.

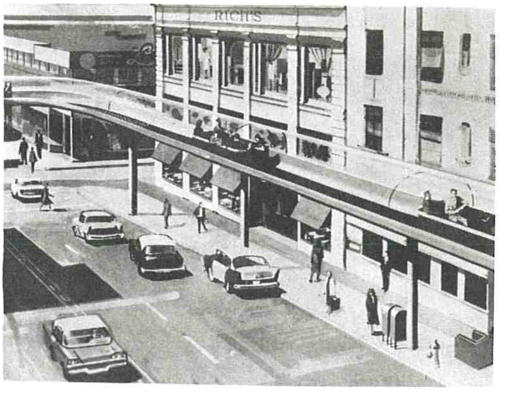

Figure 7. Carveyor system, Stephens-Adamson Manufacturing Company.

SELECTION OF HARDWARE

The wide range of alternatives available for mass transportation applications in the future makes it important to establish criteria and guidelines for the proper selection of equipment. This can best be accomplished through an iterative process encompassing a threefold approach to transit system design.

1. Establish requirements for the mass transit system in terms of its function and its performance in view of expectations of potential patrons.
2. Examine presently available systems and systems in advances stages of development to determine their suitability in light of these requirements.
3. Synthesize the final system employing the best features of each mode and attempting to meet all projected requirements.

As indicated previously, this process is iterative, i.e., repeated several times, each time making further refinement. For example, some design features must be known factors in order to develop final criteria for system capacity and guideway parameters.

The first step in the process is to establish a set of functional and environmental criteria against which performance of potential systems can be measured. These criteria include some of the following items.

Capacity

Mass transportation systems currently available have capacities ranging from 7,000 persons per hour for buses on city streets up to 10 times that for high-speed rapid transit trains. Between those capacity ranges lie many gradations, for example, busways with standard urban coaches running on high-speed exclusive bus roadways. Capacities for these systems can range from 20,000 to 30,000 persons per hour in an urban application. One capacity step below the busway is the urban streetcar (Fig. 8). This example from Düsseldorf shows an urban tram with wide doors (much like PCC cars, which were once widely used in this country) for which capacities can range up to 10,000 persons per hour. A variation of this mode is the articulated streetcar shown in an example from Rotterdam (Fig. 9). These cars are capable of achieving higher capacities and can range up to 20,000 persons per hour. Similar capacities can be attained with SAFEGE monorails and the Westinghouse Skybus.

Performance

One attribute for which the public looks when choosing a travel mode is high speed. Most efforts at developing new systems have valued high-speed operations as a major

Figure 8. Urban tram car, Düsseldorf.

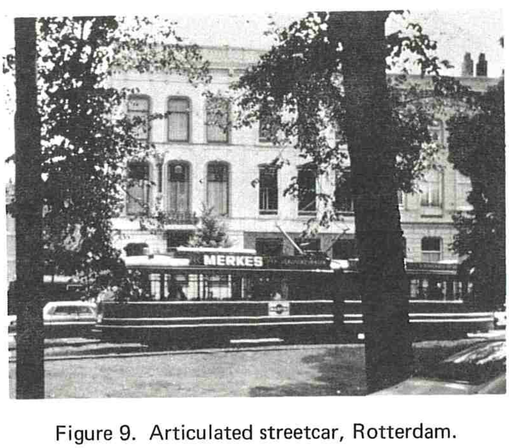

Figure 9. Articulated streetcar, Rotterdam.

improvement. The speed of urban systems is in most cases not a function of the vehicle but, rather, the route over which it operates; rapid transit, streetcars, and buses are all capable of speeds in excess of 50 mph with proper isolation from surface traffic.

Guideways

The need for special track structures affects other attributes of mass transportation systems, such as route flexibility and speed. When systems do need special elevated guideways, important aesthetic considerations are involved. In the case of small vehicle systems such as the Minirail, the aesthetic problems are usually reduced by the slenderness of the structure, as shown in the application over water in Lausanne (Fig. 10). In Munich, the system was integrated into a pedestrian walkway with landscaping to form a pleasant structure. The new Delaware River rapid transit system has designed slender concrete structures that blend into the surroundings (Fig. 11). In Rotterdam, the total system was designed as an integral structural unit with articulated rapid transit cars having 3 trucks to lower the load per truck to such a point that elevated spans of 150 ft with very slender beams were possible. Small vehicle systems have been advantageous in some cases for elevated application because they have a great deal more flexibility in terms of curvature and grade-climbing ability and can be woven into existing development patterns.

Operating Environment

This is not usually a major problem except for extremes of temperature, precipitation, and wind. Rubber-tired systems, of course, have some difficulty in colder climates with high snowfall rates.

Safety

This consideration must not be compromised. The twofold effect of safety is, of course, first, to protect passengers and, second, to reduce claim expenses to a minimum level.

Passenger Environment

This is an important consideration, and any system must be responsive to the desires and limitations of the people who are expected to use it. This is an end in itself as well as an essential part of the attractiveness of the system to potential patrons. Principal factors in environmental control are temperature, humidity, air movement,

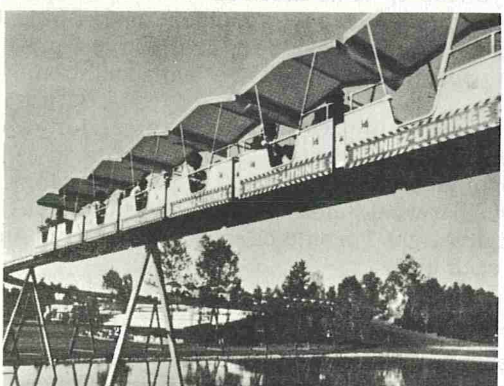

Figure 10. Minirail, overwater application, Lausanne.

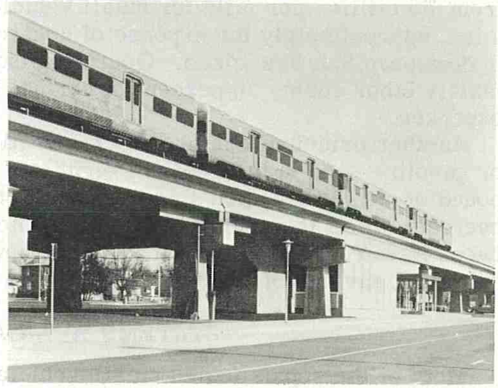

Figure 11. Delaware River Port Authority high-speed line, New Jersey.

acoustic interference, vibration, and acceleration control. Environmental considerations were of primary importance in the design of General Motors new RTS bus (Fig. 12). This coach was developed for patron comfort and includes such unusual features as an air suspension system that "kneels down" to reduce step height upon coming to a stop. Inside the vehicle, temperatures are controlled in 6 separate heating-cooling zones; and, in a deluxe version, the number of seats has been reduced to 29 to provide room and comfort for all passengers. To obtain the glass areas shown in the illustration, the body was changed from the previous semi-monocoque design, in which the exterior of the body forms integral structural components, to a separate chassis relieving the body of its stress-bearing duties.

Figure 12. RTS motorbus, General Motors.

Externalities

This category of criteria includes structural aesthetics, air-borne noise, transmission of vibration from structures to other buildings, and generation of noxious substances. External noise on small vehicle systems and most rubber-tired applications has been reduced to reasonable levels. Much research has gone into reducing sound levels of rail rapid transit, and a well-maintained, carefully baffled system can approach quite reasonable noise levels. The question of air pollution is, of course, a major consideration today; all electric systems remove that problem from the vehicle to the generating plant. Nonelectrified systems are being developed now to replace the internal combustion engine. Current research is directed at steam engines, battery-operated vehicles, and a recently revived external combustion cycle.

COST CONSIDERATIONS

Capital and operating expenses are of vital concern in the selection of mass transportation hardware, inasmuch as planners must inevitably confront the question of how to finance any improvement. In some cases, captial expenditures can be used to reduce operating costs. In other cases, added operating expenses can be used to lower capital cost, as was demonstrated by the Rotterdam experience. Capital costs may range from $40,000 for an air-conditioned bus to almost a quarter of a million dollars for a high-capacity rapid transit train, while capital expense for guideways may range from $5 million per mile for small vehicle systems up to as much as $65 million per mile, approximately the expense of constructing the BART subway under Market Street in downtown San Francisco. Operating expenses in most transit applications are primarily labor costs; 70 percent of normal bus operating expenses are transportation expenses.

Another principal component of operating expenses is power—whether electricity or gasoline—and in both cases weight is a significant contributor. For example, a pound of weight saved on a rapid transit car can yield $1.50 to $2.00 in power savings over the life of the vehicle. In dollar amount, that would mean that the difference between New York rapid transit cars and new lightweight Toronto cars would result in an operating savings of $50,000 over the life of each car.

SYSTEMS AVAILABLE AT PRESENT

Most of the sophisticated small-vehicle computerized systems are only in the concept stage. However, urban transportation problems are present and pressing. What tools are available to solve current problems? As indicated earlier, most current

Figure 13. AC Transit articulated bus.

Figure 14. British double-decker bus.

Figure 15. Airport bus, Frankfurt, Germany.

Figure 16. City bus, Düsseldorf.

Figure 17. Urban motorbus, tandem-axle, Bedford.

hardware problems are solved with either the standard GM coach or the high-speed rapid transit car. However, a wide variety of transportation tools is already available and many of them are in existence in this country. AC Transit has been experimenting with an articulated 70-passenger bus in high-speed transportation service (Fig. 13). This has proved to be an effective form of highway rapid transit operation. Small-vehicle Minibus systems are operating in a few locations.

In Europe, the wide-ranging usage of special vehicle designs for highway operation, as compared with the prevalence of the standard GM coach in the United States, is impressive. Figure 14 shows the famous British double-decker bus designed specifically for narrow streets and short turning radii. The airport bus in Frankfurt (Fig. 15), with a number of large pop-out doors designed specifically to provide floor-level loading, transports air travelers between the terminal and the airplane in much the same fashion as the special Lounge at the Dulles International Airport. A basic difference between these buses and the Dulles Lounges is a cost saving of over $200,000. The Düsseldorf city bus shown in Figure 16 provides wide entrance and exit doors specifically designed for fast loading and unloading. A careful look at the bus shown in Figure

17 shows that the front wheels are on a pair of tandem axles. This permits easy steering without power assistance and also enables the use of 13-in. tires because the engine load is distributed over more wheels.

It is apparent from this brief look at present and prospective hardware types that the transportation planner has a number of tools at his disposal, each designed for a specific application. The challenge is to match the equipment with the situation to achieve an optimum solution for each mobility problem.

Minicar Transit System—Description and Evaluation of a New Concept

VUKAN R. VUCHIC, Towne School of Civil and Mechanical Engineering,
University of Pennsylvania

The Minicar Transit System (MTS) incorporates 2 new concepts: (a) a specially designed vehicle for urban travel and (b) fleet operation, i.e., renting of vehicles by the users for one or more trips. The Minicars would be picked up by the system subscribers at any of the terminals within a served area and dropped off after use at any other terminal. Technical and economic analyses and demand projections indicate that the system is feasible, though some assumptions remain to be tested in practice. Introduction of the MTS into urban areas promises to increase mobility, reduce parking space requirements by 50 to 70 percent, increase street capacities in central cities by 10 to 20 percent, reduce air pollution, and bring other benefits. Among the problems of MTS are the uncertainties about its public acceptance and some operational aspects. Several possible types of applications of the system are discussed, and its basic characteristics are evaluated. The MTS offers personal transportation without automobile ownership. It improves mobility and reduces negative side effects of individual transportation. Its use is limited, however, to drivers and to terminals for vehicle pick-up and drop-off. Subject to satisfactory solution of some uncertainties, introduction of an MTS into urban areas would have a significantly positive impact on individual transportation that is presently unsatisfactory. Characteristics of the MTS would enable users to select the best mode for each trip and thus lead toward the optimal intermodal distribution of travel in urban areas.

•THE FEASIBILITY, desirability, conceptual development, and subsequent implementation of a new concept in urban transportation were under study at the University of Pennsylvania between 1967 and 1969. Philadelphia was selected for study and considered for eventual experimentation with this concept, designated as the Minicar Transit System (MTS). Conceptual development and feasibility analyses have been carried out at the University; the vehicle was initially studied by General Motors Research Laboratories and subsequently developed by Minicars, Inc., of Santa Barbara, California, as subcontractors to the University. The project was sponsored by the U. S. Department of Housing and Urban Development and later by the Urban Mass Transit Administration of the U. S. Department of Transportation. Some results of this study are reported here.

INDIVIDUAL TRANSPORTATION IN URBAN AREAS

Considerable investments and efforts have been made to accommodate and improve automobile traffic in urban areas. The results of these efforts are visible, but conditions of individual travel in cities, i.e., travel by private automobiles and taxis, remain unsatisfactory. Frequent congestion and inadequate parking facilities, particularly

Paper sponsored by Committee on Future Concepts and presented at the 49th Annual Meeting.

in city centers, cause low travel speeds, low trip-time reliability of travel on urban streets, high cost, and inconvenience to the users. In general, the urban transportation service, or mobility, is at an unsatisfactory level (1, 2).

Among urban travelers, automobile users suffer the greatest direct losses from these conditions; users of surface transit are also affected. In addition, there are a number of direct and indirect negative side effects on the urban environment and activities, such as excessive space requirements, air pollution, noise, and the economic inefficiency in general.

Incompatibility of the individual (automobile) transportation system and the high-density urban environment is to a certain extent unavoidable: Demand for individual automobile transportation in such areas is often higher than the available capacity of the street and highway network. The problem can, however, be reduced through adaptation of the automobile transportation system to urban conditions. This approach has been generally neglected. Most of the attention has been given to construction of freeways, while very little has been done for the improvements of facilities that are more compatible with the urban environment. The vehicles—passenger automobiles—are designed in their dimensions, performance, and side effects for long-distance travel, not for specific urban conditions.

THE MINICAR STUDY GOALS

The basic goals of the Minicar study were to analyze and plan for (a) increased mobility (higher speed, reliability of travel time, convenience, and/or reduced cost) and (b) reduced negative side effects (air pollution, space requirements, and the like) of individual transportation in urban areas by introducing a system specially designed and operated for such conditions—Minicar Transit System (MTS). The basic new features of the MTS are specially designed vehicles and fleet (instead of private) ownership and operation.

The Minicar study included not only the design and operation of an MTS but also the analysis of its various direct and indirect impacts on other modes of transportation and on the city in general.

PURPOSE AND SCOPE OF THE PAPER

The primary purpose of this paper is to evaluate the MTS concept: It presents the system's positive features and its deficiencies, and discusses its potential optimal role among other modes in urban transportation.

To discuss the system's characteristics and evaluate its role, it is necessary to present a description of the MTS as it is currently conceived—its operation, physical components, and functional aspects. Because of space limitations, the presentation of the system is given only to the extent necessary for its evaluation. More detailed results of the research, including various data, methodology, and technical results, as well as economic analyses, demand projections, legal aspects, and the like can be found in the published (3, 4) and internal (5, 6) research reports on the Minicar study.

SYSTEM DESCRIPTION

MTS Operation

The Minicar Transit System consists of a set of terminals located at many points throughout a served area and a fleet of specially designed vehicles—Minicars. Any person who satisfies certain requirements with respect to driving ability, insurability, and credit can become an MTS user. The user has a credit card that allows him to rent a Minicar at any of the terminals for a single trip, or for an extended period of time, after which he can drop the Minicar off at any other terminal. The times and locations of the checking out and checking in of the vehicle are recorded and transferred via an information system to the central facility. Charges for the use of the Minicar are computed on the basis of time and mileage between the 2 check points. The user does not worry about the fueling and maintenance of the vehicle; the insurance and parking are included in the charges, unless the user parks at a facility not belonging to the MTS.

The Vehicle

To derive full benefits from the MTS for the users, the operator, and the city, the vehicle has to be adapted to the requirements of its applications. Inasmuch as Minicar use would differ considerably from operation of any other vehicle systems, it is clear that a vehicle of special design is called for.

Vehicle specifications have been developed on the basis of different sets of requirements and fundamentally changed several times in the course of the study as the concept of the MTS was modified. At different stages of the study a number of unorthodox features with respect to vehicle dimensions, form, propulsion system, interior design, maintenance, and other elements were considered. For example, at one point a special type of door was analyzed that would open all around the vehicle, i.e., also through the roof, so that the passenger could step into the vehicle standing, sit, and then close the door. The main features of the current concept are summarized in the following.

Dimensions—To minimize space requirements of this urban vehicle in the streets and particularly in the parking facilities, the basic objective is to minimize the length of the Minicar, subject to the constraints of vehicle performance, passenger comfort, and safety. It was found that an overall length of 9 ft, or approximately one-half of the average standard American car, is the minimum dimension that still satisfies these requirements. This dimension, including one foot of front overhang, allows the vehicle to be parked perpendicularly to the curb within the standard 9- or 10-foot wide parking lane, thus occupying only approximately 30 percent of the curb length required for a standard parallel curb parking space.

Because the Minicars will not utilize special lanes or guideways (at least in the first stage of development), no savings in lane widths can be achieved by reducing the vehicle width. Thus, the width has been determined so that the vehicle can accommodate 3 passengers, a capacity that is considered minimum for the purpose of the system. Presently the width of the Minicar is planned to be 78 in., and a maximum outside height is 59 in. The curb weight of the vehicle (full fuel tank, no passengers) is estimated at 2,250 lb. A Minicar prototype model is shown in Figure 1.

Performance and Propulsion—Inasmuch as the Minicars will utilize the existing streets and highways of all types, they must have adequate dynamic characteristics to perform satisfactorily in mixed traffic on both local and high-speed facilities, including freeways. Consequently, a high rate of initial acceleration and high top speed are called for. Reasons of economy, minimum air pollution, and noise require that the motor be as small as possible. Based on an examination of a number of different types of propulsion, it was found that the optimal propulsion system would consist of an internal combustion engine (ICE) and an electric motor. The 2 units and the battery are interconnected so that the ICE acts as the main propulsion unit; during the idling periods, it rotates the electric motor, which is in that case connected as a generator and it charges the battery. In the periods of peak tractive effort, such as initial acceleration, the electric motor is activated to contribute to the required power output. This operational feature reduces maximum requirements for the ICE and allows use of an engine with very low power rating. Current specifications call for an ICE that will provide a net tractive effort at the wheels of 38 hp; an additional maximum of 20 hp can be delivered by the electric motor.

Figure 1. Minicar prototype.

This propulsion system has a number of advantages over standard systems. It provides the excellent tractive characteristics of the electric motor, while extending the operating radius well beyond the capacity of the battery because the fuel tank (via the ICE) becomes the determinant.

It permits use of a small ICE, expected to result in considerable fuel economy and extremely low levels of air pollution. An additional and particularly important feature is that the vehicle will be capable of operating for a certain period of time on the electric power only. This will allow its use in closed areas without problems of ventilation.

Admittedly, this propulsion system is more complicated than the standard systems; however, it is technically feasible, and its reliability will be increased by the feature that either of the 2 motors can work independently if the other one is disabled.

Passenger Aspects—The Minicar has adequate dimensions for 3 seated passengers as well as for easy entering and exiting. The steering wheel and foot pedals are movable so that each driver can adjust them according to his size without moving the seat. Special attention is given to the safety features of this vehicle with the objective of making it at least as safe as standard automobiles. The vehicle body and interior combine an impression of simplicity and elegance with a design that is conducive to easy maintenance and resistant to vandalism.

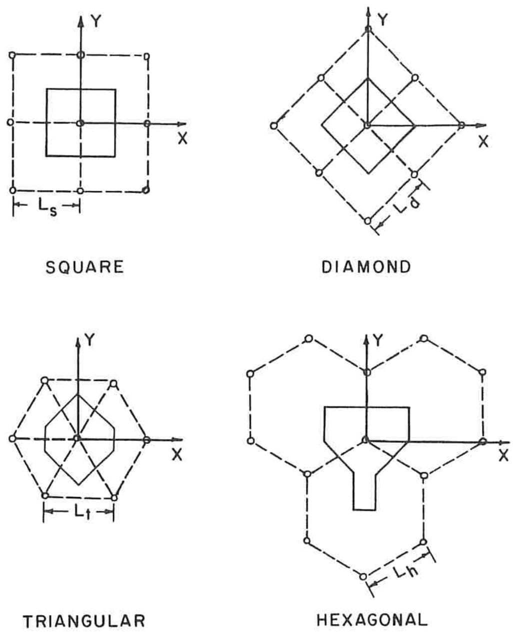

Figure 2. Terminal location patterns.

Other Features—The Minicar has a number of other novel features providing for information transfer at vehicle check-out and check-in, high technical reliability, and easy maintenance (a special diagnostic system).

Terminals

Various aspects of terminals have been analyzed in considerable detail. The studies included the optimum locations, size, and density of terminals; internal operations and design; and implementation aspects in general as well as specific ones for Philadelphia.

A theoretical study was undertaken to establish which geometric pattern of terminal locations requires minimum average and minimum maximum walking distances in an area for a constant density of terminals. Four geometric patterns were studied: square, diamond, triangular, and hexagonal (Fig. 2). For the assumption that there is a ubiquitous transportation network, which is usually adopted in location theory analyses, the hexagonal service areas result in the minimum average walking distance for a given density of terminals and the requirement that the whole area be served. This assumption, however, is not very realistic for an urban situation; a street pattern in the form of gridiron was considered more typical so that the assumption of such a network was

TABLE 1

ACCESS DISTANCES FOR ALTERNATIVE TERMINAL PATTERNS

Terminal Pattern	Distance in Terms of			
	Respective L's		L_s	
	$\overline{D}$	D_{max}	$\overline{D}$	D_{max}
Square	$0.050L_s$	$1.00L_s$	$0.50L_s$	$1.00L_s$
Diamond	$0.471L_d$	$0.71L_d$	$0.47L_s$	$0.71L_s$
Triangular	$0.44L_t$	$0.68L_t$	$0.48L_s$	$0.73L_s$
Hexagonal	$0.58L_h$	$1.18L_h$	$0.51L_s$	$1.04L_s$

Note: $\overline{D}$ = average access distance and D_{max} = maximum access distance.

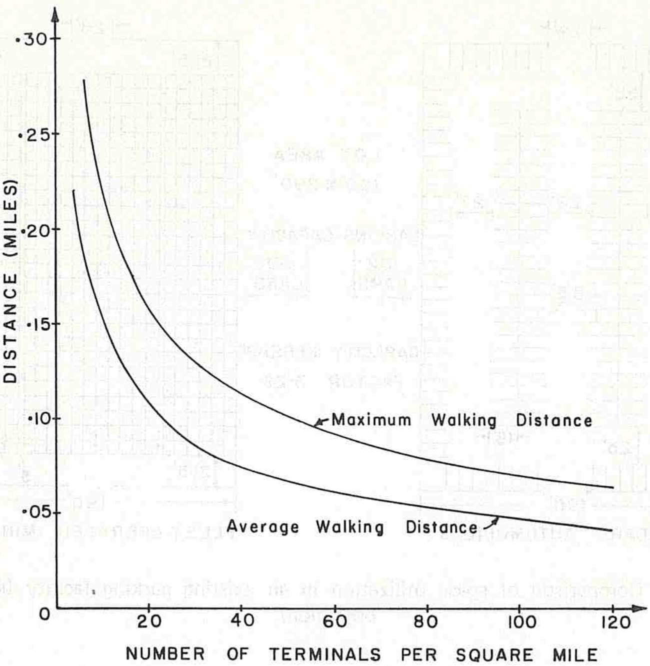

Figure 3. Access distance as a function of terminal density.

made (streets follow directions of x and y axes shown in Figure 2). The results of this analysis, given in Table 1, indicate that the diamond pattern of terminals is the optimal one with respect to both criteria: average and maximum walking distances. The diagram shown in Figure 3 gives average and maximum walking distances as functions of terminal density for the diamond pattern.

The optimum size and density of terminals, subject to the optimal locational pattern and local conditions such as access street network, traffic volume, and access point locations, are based on the trade-off between the user walking and cost of provision and operation of terminals, as well as some less important factors. An additional complication is created by the fact that the total number of system users is a function of terminal density. A parametric model including all these factors is being currently analyzed.

Because of 2 characteristics of the Minicars—their fleet operation and vehicle dimensions—their parking space requirements are considerably smaller than the requirements for standard privately owned automobiles. This represents one of the major benefits expected from the MTS. Comparison of the parking capacities required for Minicars versus private standard automobiles, shown in Figure 4, has been made for a facility that has optimal dimensions for parking of private automobiles, to guarantee that the derived figure is conservative. The results of this analysis give the following parking capacity increase factors:

Vehicle	Standard Automobiles	Minicars
Privately owned	100	206-232
Fleet operated	157	324-364

To obtain a comparison between the required terminal space for the entire MTS with parking requirements for private automobiles on a per trip basis, space requirements

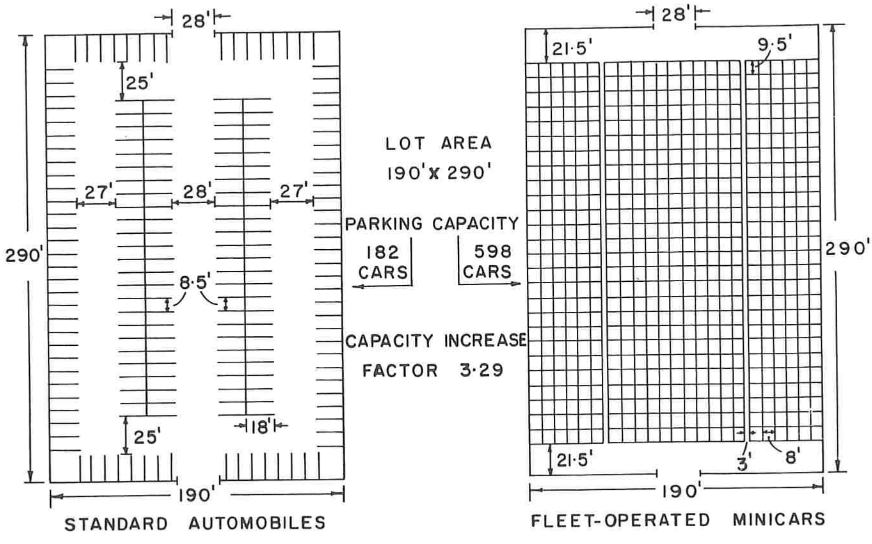

Figure 4. Comparison of space utilization in an existing parking facility (self-parking operation).

for other functions in terminals as well as turnover rates and area utilization factors must be included for both systems. This study has not yet been completed.

Maximum operational efficiency of terminals would be obtained by special design of facilities. However, this would require considerable investment, particularly in the initial stages of system implementation; it has been found satisfactory that the MTS would, at least in the initial stages, utilize sections of, or the whole, existing parking facilities. The facilities would be leased from the operators (public or private). It is expected that such an arrangement would not only minimize investment requirements but also result in economies of labor: The same parking attendant could be used for private car parking and for the MTS terminal.

Ways

Minicars would utilize the existing street and highway network, so that no special way facilities are foreseen. This has operational disadvantages, but also represents an extremely important advantage of the MTS with respect to its implementation. At the same time, the possibility of bimodal and fully automated operation in subsequent stages of development are open, and they are being studied.

Fairly extensive studies of the impact of vehicle size on traffic flow have been performed (3, 4, 5, 6). They included a field survey, theoretical analysis, and computer simulation. Some results of these studies are shown on a flow-speed diagram in Figure 5. They indicate that the use of very short vehicles (such as 9-ft long Minicars) instead of standard automobiles would result in an increase of traffic flow of 30 to 50 percent in heavily congested areas (for one case with extreme congestion and somewhat special conditions, the simulation has shown that the increase might be as high as 70 percent). The increase of flow decreases with increase of speed and becomes negligible at the normal speed of traffic flowing on freeways. For typical conditions on downtown streets in urban areas, the improvement may be expected to lie in the range between 10 and 20 percent. It can be shown, however, that for a constant input of vehicles this increase in flow would result in a disproportionately greater reduction of queues and travel times. For example, at such critical locations as bridges or tunnels that are presently congested the expected increase of the flow rate of only 7.5 percent

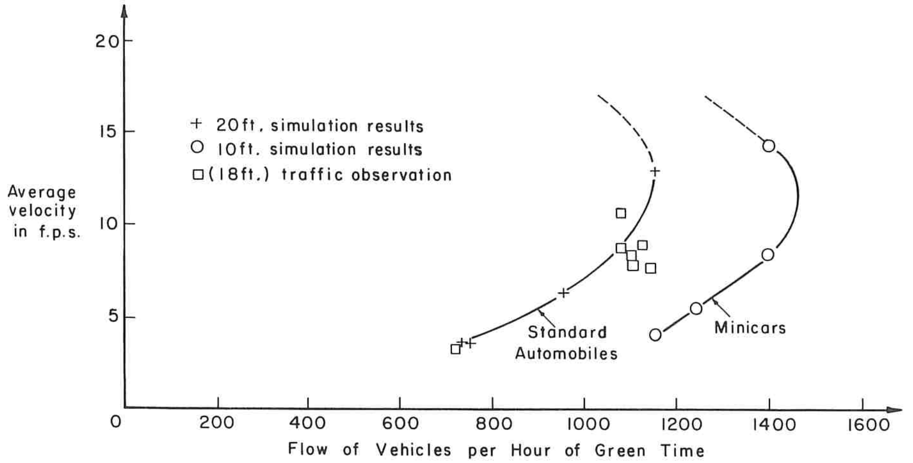

Figure 5. Traffic flow characteristics.

(50 percent Minicars) would result in a reduction of queue length by 35 percent and reduction of total delay by 29 percent (6).

FUNCTIONAL ASPECTS

Types of MTS Applications

To offer a high level of service, MTS must provide a considerable density of terminals, so that users can always find a Minicar within an acceptable walking distance. This requirement can be best satisfied in high density areas, that is, in the CBD. Because the benefits from the MTS would, because of its impact on congestion, parking, air pollution, and other problems, be highest in the high-density areas, central urban areas are logical ones for primary utilization of this system. Two different basic uses of Minicars have been foreseen in relation to these areas: intra-central-city trips and commuting trips to the central area.

Trips within central urban areas are performed by walking, public transportation, taxi, or private automobile. The shares of each of these modes depend on city size, availability of different modes, and a number of other factors. Very detailed analyses of travel time components for each of these modes in typical situations indicate that for very short trips (up to approximately 1,500 ft) walking is the fastest mode of travel. Bus and subway offer the minimum travel time for distances between 1,500 ft and 1 to 2 miles. Beyond this distance, the subway is the fastest where it is available. In other areas, the individual transportation—taxi, private automobile, and Minicar—have superior speed.

The ranges of these values are broad because they depend heavily on availability of public transportation (area coverage) and type of parking facilities and MTS terminals. A diagram representing one of the studied typical trips is shown in Figure 6. The case is typical for intra-CBD travel so that it indicates good area coverage (short terminal times) for bus and subway and inconvenient parking (long terminal times) for car and Minicar. Therefore, this case is conservative for the Minicar. Yet the MTS shows superiority (minimum travel time) for distances over 2.2 miles, except where it directly competes with a subway line. For trips that do not follow public transportation lines, the Minicar offers shorter travel time even for distances as short as one mile in the central urban areas.

Demand projections for MTS in central Philadelphia (3) were based on the "total cost" of travel, consisting of direct and indirect monetary costs and travel time for

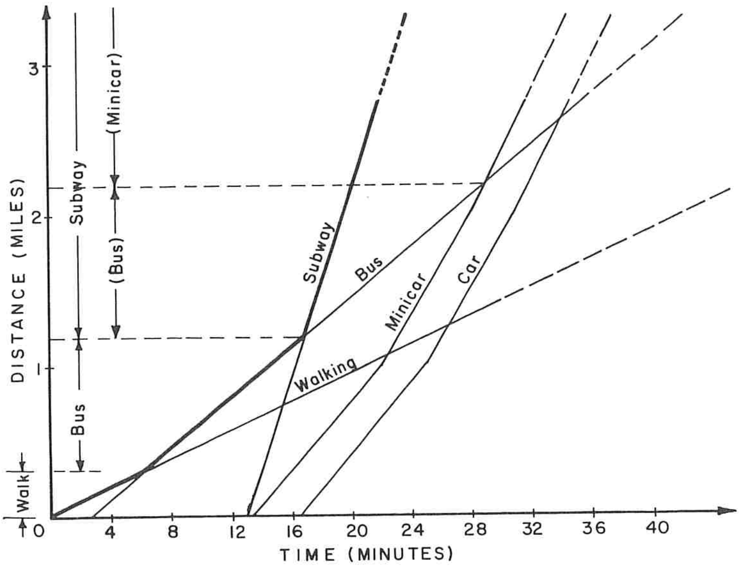

Figure 6. Comparison of CBD travel by different modes.

TABLE 2

AN EXAMPLE OF PROJECTED TRIP DIVERSIONS TO THE MTS IN PHILADELPHIA, 1975

Trips	Intra-CBD	CBD Fringe	Intra-Fringe	Total
Divertible + nondivertible	78,406	241,157	474,971	905,526
Taxi	23,892	17,382	38,116	79,390
Transit	20,462	107,943	100,971	299,376
Automobile	34,052	115,832	335,884	485,760
Railroad	–	–	–	111,000
Divertible	49,452	149,299	335,227	534,248
Taxi	12,535	8,976	19,535	41,046
Transit	8,185	43,178	40,389	91,752
Automobile	28,732	97,415	275,303	401,450
Percent diverted from divertibles based on $0.50 initial fare	67.2	32.1	5.2	18.5
Taxi	49.8	49.1	47.2	48.4
Transit	27.8	20.7	20.7	21.3
Automobile	86.0	35.5	0.0	14.8

Note: At parking rate of $0.75.

each mode. Trips by the existing modes, projected for 1975 and obtained from the Delaware Valley Regional Planning Commission, were divided into divertible and nondivertible (i.e., groups of more than 3 persons and other kinds of trips that cannot be served by MTS); diversion was then estimated by synthetic diversion curves for individual categories of trips. To be on the conservative side, no generated trips were included.

Demand projections were made for several different sets of parameters. To examine sensitivity, minimum rates for Minicar use and value of travel time were given several values. One of the sets of demand projections by mode and area of travel is given in Table 2. Though this set is presented as an example rather than the final demand projection for the MTS, it indicates some typical relationships. Most of the diverted trips come from private automobiles. Diversion from taxis is also appreciable, but public transportation loses relatively few passengers to MTS.

The second major application of Minicars is for commuting to and from the city. Inasmuch as commuting trips take place at different times from most of the trips within the city, these 2 uses would be complementary, thus allowing better utilization of the vehicles and lower fixed charges per trip. While rates for trips within the central area would be graduated according to distance and duration of use, commuting trips would be charged at a flat rate per month, regardless of the mileage. Thus the monthly fee would cover the commuting and any additional trips during the evening up to the

mileage limit imposed by the fuel supply; it would include parking at MTS terminals. The economic feasibility studies for Philadelphia indicate that these monthly charges would be in the vicinity of $80. In comparison with the estimates of the cost of commuting by private automobile (7), particularly for large cities in which parking charges in central areas are quite substantial, this monthly charge would be competitive with the costs of commuting by new private automobile or relatively new at the time of purchase, when the user compares total charges. This price would not be competitive with older, depreciated vehicles or free parking. Because of the option of selecting different parking terminals in the city, lack of maintenance problems, and other advantages of the Minicar use, it has been estimated that there would be considerable potential for diversion of people from their automobiles to the Minicars (this number has been estimated at approximately 23,500 vehicles for Philadelphia, 10 years after the system's introduction). Actually, the number of vehicles required for commuting would be greater than the number required for trips within the central area.

There are several other types of potential Minicar uses that require further study and demonstration. In all these cases it is clear that there would be considerable benefits from the application of Minicars; the problem in some of those cases is the uncertainty about the economic feasibility of the system due to the limited utilization of vehicles. Several examples of such additional uses are described here.

Use of Minicars as feeders for rapid transit systems in suburban areas is in some respects more convenient than their use in central areas. The distances traveled by suburbanities to the rapid transit stations are usually greater than the trip lengths within the central areas; traffic congestion on the streets is lower; and availability of land for terminals at the stations is greater. The main problem is securing sufficient utilization of vehicles that would permit acceptable rates for their use. In cases where rapid transit stations are located beyond walking distance from other traffic generators, the Minicars would be utilized only for approximately 2 trips per day, thus requiring excessive rates to achieve the system's economic feasibility. In the cases in which the station is in the immediate vicinity of high-density apartments, the Minicars could be used during the day by the apartment dwellers for their shopping and other trips, thus increasing vehicle utilization and permitting lower per trip charges.

Travel from inner urban areas to the suburban locations ("reverse commuting"), which has become a particularly serious problem for low-income residents, would be another desirable use for Minicars. Suburban workers who live in the city could either drive Minicars from their homes or take a commuter train to a suburban station, where they would pick up Minicars and drive to their work locations. In some cases the timing would be such that suburban commuters and reverse commuters could use the same vehicles. The remaining problem is again to find a supplementary use for the vehicle once the worker has arrived at the suburban plant. There are 2 possibilities for covering the cost of this use of Minicars: The plants may use them during the day for travel by business officials or messengers and other supporting personnel; the other possibility for maintaining the economics of the MTS would be a certain amount of subsidy by the plant for Minicar commuters, on the basis of the reduced terminal requirements (as compared with parking facilities for private automobiles), or for social reasons in cases of low-income workers.

Relationship to Other Modes

The main objective with respect to the relationship of the MTS with other modes is to maximize diversion of trips from private automobiles to Minicars in order to reduce the high social costs of private automobile use in the cities. The Minicars can substitute for private cars without negatively affecting the ease of individual travel. Actually, mobility would be increased. In some cities diversion from taxis is also desirable because taxi companies are not in a position (because of labor and other problems) to satisfy the demand for this type of service. Minicars would thus meet the latent demand for rental travel. Diversion of trips from public transportation should be kept to a minimum because of the potentially negative effect on the economics of public transport operation and on increased congestion in the streets. Although it will not be

possible to prevent any diversion from public transportation, it is expected that Minicars will, on the other hand, increase the number of public transportation trips by providing better collection-distribution service in the city and eventually in the suburbs than is now available.

To achieve a desirable pattern of trip diversions, considerable experimenting with the pricing of Minicars will be necessary, at least in the initial stages. It would also be desirable to have some coordination and control of charges for competitive services, such as, for example, parking rate level and structure in the city.

Population Groups as MTS Users

Several different categories of urban population could be users of Minicars in their different applications. Urban residents would have Minicars available for short trips in the city, a service that would allow some of them not to own private automobiles, thus saving on parking, maintenance, and other expenses. Suburban commuters would use Minicars either for their whole commuting trips or for collection and distribution at either end of their trips by public transportation. As mentioned earlier, there is a possibility that residents of low-income areas may use Minicars for their trips to the suburban employment locations not served by public transportation. Businesses within the central area as well as those in the suburbs could use Minicars for business trips by their management personnel, employees, or for their visitors. In addition, some companies and government agencies that use fleets of vehicles could rent Minicars at considerable savings in comparison with rented standard automobiles. Such users include the post office, insurance and service companies, various traveling salesmen, and other similar businesses.

SYSTEM EVALUATION

Benefits From a Minicar Transit System

Benefits from introduction of a Minicar Transit System into an urban area will be summarized and reviewed here. They can be classified into user and social, and each of these can be divided into direct and indirect benefits.

Direct user benefits include such items as greater availability (choice) of transportation service, so that the user can select the service that best corresponds to the need of a particular trip. There would be user benefits from all diverted trips because each person would change mode to realize a gain in the form of reduced cost or travel time, increased convenience, and the like.

The indirect user benefits are those accrued by the greater mobility of individuals. Easier travel and increased choice of destinations for work, recreation, and other activities would be some of these benefits.

Direct social benefits include such items as lower parking space requirements, resulting in reduced investments for parking facilities as well as availability of the space for other purposes, and improved traffic flow in the streets and arterials, resulting in lower cost of transportation and reduced side effects of congestion. As shown earlier, these benefits would be of considerable magnitude.

Reduced air pollution and noise due to the introduction of an MTS would be beneficial for improvement of the urban environment in general. Analyses indicate that the overall improvement in the city would be negligible, but at individual congested locations it would be quite significant.

Increased mobility of population would also represent an indirect social benefit, because mobility plays an important role in the living standard of the population and efficiency of urban economy in general. Through the long-range effects increased mobility would have another indirect social benefit on the city—increased options for urban physical developments.

Development of transportation technology as well as increased possibilities for testing of different types of transportation services (renting in particular) would be another significant spillover of the MTS.

Potential Problems of the System

Because of the complexity of urban transportation, planning of an entirely new system without direct testing is extremely difficult and some uncertainties cannot be avoided. Some of the present problems with respect to the MTS are likely to be resolved after some experience with the system's operations is obtained; some others may remain and even become critical for feasibility of the whole system.

The most critical uncertainty about the MTS is its acceptability by the public. Demand projections for the system indicate that Minicars will be competitive with other modes, particularly private automobiles and taxis, with respect to cost and time of travel. Based on these quantitative criteria, the usage of Minicars is expected to be rather high (Table 2). The projections are, however, limited by the state of the art in predicting demand for entirely new modes. There is, for example, still no reliable method for quantitative predictions of such factors as acceptability of rented self-driven personal vehicles, willingness of users to pay total charges for travel (a good portion of which is hidden in the use of private automobiles), various aspects of terminal operations, and driving of a different vehicle. All these factors may influence public acceptability of the MTS.

Although these uncertainties about public acceptance can be positively resolved only through a demonstration of the system, some significant information can be obtained through various opinion surveys and marketing-type research. A considerable amount of such information has been obtained, particularly through a "product clinic"—an exhibit that was organized in Philadelphia with interviews with a number of groups representing potential users, government officials, and other interested groups. The responses obtained in these surveys have been in general very favorable for the system, giving considerable ground for optimism with respect to the uncertainties about user acceptance.

Most of the system's elements have been resolved at least at the conceptual level. Major ones that require additional research and development are some problems of vehicle redistribution among terminals and degree of automation of terminals (full automation of some of the terminals is being studied). Vandalism is another aspect that is very difficult to quantitatively predict; it requires actual experience.

Finally, if many trips by modes presently not occupying streets (railroads, subways, walking) are diverted to Minicars, the increased number of trips may more than offset the increase in traffic flow due to the shorter length of Minicars. Congestion problems may also exist because of the ease of renting the Minicars. A rapid storm, for example, may cause pedestrians to try to rent Minicars, and thus create unpredictable congestion. Special events create similar problems, and it will be necessary to introduce certain limitations on renting Minicars on such occasions.

Analysis of the MTS Concept

Each of the 2 unique concepts of the Minicar Transit System—specially designed vehicles for urban service and fleet operation—gives the system, in comparison with other urban transportation systems, certain advantages as well as drawbacks and limitations. At a risk of some repetition, it appears worthwhile to review them briefly.

Advantages—MTS combines the advantage of individual travel (personal routing and personal schedule) of the private automobile with the availability of common carriers: Users can travel without owning a vehicle.

Both concepts contribute, in varying degree, to the benefits that MTS potentially offers. For example, lower parking space requirements are due to both special vehicle design and fleet operation; acceptability by users depends on the vehicle itself as well as on the ease of obtaining it.

Both concepts also contribute to the economic advantages of the system. The specially designed vehicle provides for maximum reliability and minimum maintenance costs; shared use reduces the cost per trip. These items represent a major portion of the cost advantage of Minicars over private automobiles.

In the long run high flexibility of Minicar use due to the ease of renting and dropping it off at any time is likely to permit easier adjustment of traffic to the urban conditions.

If, for example, traffic flow reaches capacity and congestion occurs, it is likely that some of the drivers will decide to drop their Minicars off at the nearest terminal (which option they do not have if they are using their own automobiles) and use another mode. Greater number of combinations of modes can be made for every trip, so that the congestion level at which tolerance (or intolerance) of drivers is reached and they begin to look for alternate modes or times of travel is likely to be lower than at present, with more limited choice of travel combinations. Thus it may be expected that, in general, the traffic situation will improve because of the MTS characteristics. Easy implementation of the MTS due to the compatibility of Minicars with the street network is one of the major advantages of the system. The system does, however, require a certain scale in order to provide its maximum efficiency; although it is small, the number of terminals is limited and its utilization is therefore also limited. It is possible, however, to make a small-scale experiment with an MTS and yet derive from it conclusions about the full-scale system. The experiment must be organized with a selected, controlled group of users for certain types of trips only.

MTS also offers a number of evolutionary options. Tests with this system will provide extremely valuable information for any system based on renting of individual vehicles. If the concept of renting proves successful, MTS operation may be improved by providing separate lanes in the existing streets, separate streets entirely, or, in a further stage, special guideways leading to bimodal operation and eventual full automation.

The existence of a centrally planned and controlled system such as MTS in a city offers the authorities an effective tool for control of traffic situation, regulation, and introduction of various types of rates and eventual surcharge or subsidies for special cases as social or other reasons may require.

Limitations and Disadvantages—The same basic characteristics of the MTS create certain limitations. The major deficiency of the system is that it has a limited availability. Like private automobiles, it is limited to use by drivers only (at least as long as Minicars are operated manually, as foreseen for the first stage); like public transportation, it is available at certain points (terminals) only.

Operationally the MTS has similar limitations to those of the private automobile system: low capacity, low reliability due to congestion and inclement weather, low safety compared with public transport, and the like. Yet, in all these characteristics it is somewhat superior to the system of private standard automobiles, as was shown previously.

Opposed to the cost advantages of the MTS discussed earlier, its cost disadvantages are that the system must provide for its overhead, for special facilities (such as maintenance and information system), and for an excess in vehicle supply to achieve required reliability of finding a vehicle at any terminal. Many of these items will involve considerably lower actual total cost than the corresponding number of private automobiles would require (standardized vehicles and maintenance), but the costs of private automobiles are absorbed with less awareness by the owners than when they are directly reflected in the cost of each trip.

Potential Role of MTS in Urban Transportation

The major role of a Minicar Transit System in cities would be to serve for individual travel within central areas, as well as into and out of them. The general question is often raised, Why should there be improvements of individual travel in high-density areas that are not conducive to that type of travel and suffer from congestion caused by it? Public transportation with its high capacity is the ideal system for those areas. This comment is correct, but it neglects the fact that certain amount of individual travel within these areas is indispensable and its elimination would cause very serious negative effects. Thus, a full substitution for individual vehicular travel would have to be provided before private automobile traffic is eliminated. If such ubiquitous public transportation in these areas is not provided, then individual travel by a system well adapted to these conditions (such as MTS) is more desirable than travel by private automobiles. This has been shown in the preceding discussion of potential benefits from the MTS.

In addition to its role in central cities, several other applications of MTS, such as suburban travel and company fleet, may provide a very useful means of transportation.

Minicars would offer a service very similar to that of private automobiles. For many trips they can provide a door-to-door service. Major advantage of the system is that Minicars are easily "disposable"—they can be used for a single trip and then left. For the next trip, a different mode can be used. This eliminates the interdependency of consecutive trips, which is a negative feature of private automobiles. The Minicar is thus ideally suited for multi-ended trips and for trips after which the user would like to permanently (e.g., for more than one day) dispose of the vehicle. Most typical cases of this use are trips to the air, railroad, and bus terminals. Airport access, one of the most debated current problems in urban transportation, would particularly improve by the introduction of Minicars because the traffic volume on access highways would decrease (reduced chauffering of passengers) and parking problems would be largely alleviated.

Through the increased choice of modes and greater facility in combining them, the Minicar Transit System has potential to lead toward an efficient, integrated, multimodal urban transportation system.

ACKNOWLEDGMENTS

The preparation of this study has been financed in part through a grant made under the Urban Mass Transportation Act of 1964, which is administered by the U. S. Department of Transportation. The author of this paper wishes to give credit to a number of persons who have made significant contributions in the materials directly discussed here: M. Altman, project director; D. Friedman, Minicars, Inc.; A. Tomazinis for demand projections; L. Eisenberg for traffic flow simulation; J. Yu for terminals; research assistants B. Byrne, R. Eash, J. McClenahan, and H. Simkowitz; and several other participants of the Minicar Study. Suggestions of E. F. Bisbee in the preparation of this paper are also gratefully acknowledged.

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Algorithms for Routing and Scheduling in Demand-Responsive Transportation Systems

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This paper reviews several techniques that have been developed for the routing and scheduling of proposed demand-actuated transportation systems. These routing and scheduling techniques have been used in the computer simulation of these systems. Specifically, attention is directed toward the work at Northwestern University, Westinghouse Air Brake Company, and Massachusetts Institute of Technology. A critical review is made of these techniques, highlighting their differences, similarities, and possible limitations. Specifically, attention is given to (a) the selection of a vehicle for pickup and delivery of passengers; (b) the method of selecting priorities for the pickup and delivery of passengers; (c) the ability to handle groups of passengers with common origins and with or without common destinations; (d) the method of contact and the frequency of communication with individual vehicles; (e) the method of describing the street network characteristics of the area to be served; (f) the location of vehicle terminals; (g) the dispatching policies; and (h) the proposed levels of service. Also included is a discussion of work currently under way in the Transportation Research Department of General Motors Research Laboratories that introduces new techniques for the routing and scheduling of passengers.

•MUCH ATTENTION is being given a relatively new type of urban transportation system. This new system goes under a variety of names such as demand-scheduled bus system (DSB), dial-a-bus, demand-jitney (DJ), computer-aided routing system (CARS), and small bus operations. A variety of methods have been proposed for the routing and scheduling of individual vehicles. Computer simulation has been and is being used to evaluate such systems and to arrive at some operating decisions for a real performance or demonstration project. Each group working in this area has proposed somewhat different algorithms for the routing and scheduling of vehicles.

This paper is intended to bring together the various proposed methods and in a brief summary point out the similarities, differences, and possible limitations. Specifically, attention will be directed toward the following items:

1. The selection of a vehicle for pickup and delivery of passengers;
2. The method of selecting priorities for the pickup and delivery of passengers;
3. The ability to handle groups of passengers with common origins and with or without common destinations;
4. The method of contact and the frequency of communication with individual vehicles;
5. The method of describing the street network characteristics of the area to be served;
6. The location of vehicle terminals;

Paper sponsored by Committee on Future Concepts and presented at the 49th Annual Meeting.

7. The dispatching policies; and
8. The proposed levels of service.

Items 1, 2, and 7 are closely related. They are discussed separately in this paper to aid in the understanding of the various algorithms. This review is limited to the work done at Northwestern University, Westinghouse Air Brake Company (WABCO), and Massachusetts Institute of Technology (M. I. T.) (1, 2, 3). Also included is a discussion of work currently under way in the Transportation Research Department at General Motors Research Laboratories.

The success of a demand-scheduled bus system might well lie within the routing and scheduling ability. The operational status of the routing and scheduling algorithm will undoubtedly influence the cost of operation. There may be some trade-offs between the cost of sophisticated routing and scheduling techniques and other costs of operation. In addition to the cost of operation, the routing and scheduling technique used may well influence demand for service. How users are picked up and routed could influence the attitudinal preferences of passengers.

The algorithms discussed have been written in a variety of computer languages on several computers, including equipment manufactured by Control Data Corporation (CDC) and International Business Machine Corporation (IBM), and run under the control of various operating systems.

The Northwestern work was written in the FORTRAN language using the SPURT simulation system for the CDC 6400 computer. The General Purpose System Simulation (GPSS) software was used by WABCO. It is not clear from the reporting of the WABCO work what model of the IBM 360 was used. FORTRAN was used by M. I. T. on the IBM 360/40 and IBM 360/65 computers.

Various items that will be discussed, such as the selection of vehicle for pickup and delivery of a passenger and the method of selecting priorities for pickup and delivery of passengers, are closely related. Such divisions have been made in order to more clearly state what the various techniques are intended to do and will hopefully make them understandable.

The Appendix presents in table form a brief comparison of the various algorithms.

SELECTION OF VEHICLE FOR PICKUP AND DELIVERY OF A PASSENGER

The Northwestern University simulation program specifies methodology for picking up and delivering a given passenger. As a demand for service is received, the Northwestern program scans the location and usage of all of the vehicles that are currently operating in the system. The vehicle that is nearest (by distance) to the origin of the call is the first one selected to be considered for service. This vehicle is then checked to see if the new demand can be serviced without violating any of the passenger service criteria that have been established for passengers already on board or for those passengers that are scheduled to be picked up. If the bus that is nearest the new demand is not able to service the call, then the next nearest bus is selected and is scanned to see if it can service the new demand. After all the buses on the system have been scanned and no bus is found to be able to meet the new demand, then a bus is sent from the terminal to service the call. When a new bus is generated, it then is considered to be in the system and will be considered for any other incoming calls.

Because the closest bus is always the first one to be considered as a possible server, there is really no assurance that any optimization in level of passenger service will be obtained. In fact, at times, passengers will have to remain on the bus an additional time that might otherwise be avoided. However, at no time will any of the established levels of service be violated for any passenger on any bus. Once an individual is assigned to a given bus, he remains assigned to that bus until he is picked up and delivered to his destination.

In the WABCO simulation, a given vehicle (one of three in the service area) makes a pickup or a delivery to serve the waiter or the passenger with the highest priority. For the waiter (the passenger that is to be picked up), a priority is assigned that has an arbitrary value of 110 minus his distance from the vehicle under consideration in

grid units minus the waiter's origin to destination (O-D) distance in grid units. A grid unit is a function of the grid density; for example, in an area of 25 square miles and a 20 by 20 grid, the grid unit would have a value of 0.25 mile. For those users already on the bus, "the priority is 100 minus the destination distance in grid units plus one unit for every five minutes of total wait time plus one unit for every 10 minutes of total wait time" (3). If a passenger has been waiting for 40 minutes, including the time that he spent on the vehicle, he is assigned a top priority. The WABCO algorithm uses one additional vehicle designated to handle the longest trips and the longest waiters. This vehicle attempts to handle those passengers that cannot receive service from the other vehicles in the system. A passenger waiting to be picked up will be given a priority relating to the largest value computed by adding his O-D distance in grid units to his waiting time measured by 1 unit for 3 minutes of wait, 1 unit for 2 minutes, and 1 unit for 1 minute of wait time. If this extra vehicle cannot keep up with the task of handling the longer waiters, provision is made for other vehicles to assist by assigning a top priority to those waiting over 50 minutes.

In the M. I. T. CARS project, a vehicle is selected to serve a new demand based on the consideration of waiting time of the new user, his travel time, his overall service time, link constraints, and the travel constraints of all current users. The link constraints are, in effect, the time that a vehicle is due at particular nodes in the tour of the bus. The travel constraints of all current users are waiting time, travel time, and total service time. The new user is assigned to a vehicle that can serve him while inconveniencing "as little as possible" those already traveling and serve the new demand "quickly" and also maintain the ability to serve future demands.

If it is desired to optimize on-system operation or to minimize the cost of operation, it is obvious that the fewer the buses required to service a given demand level, other factors being equal, the more likely it is that cost will be lowered. Thus, if an algorithm is developed that would tend to maximize the occupancy of a given vehicle, then this would seem, on the surface, to reduce the number of vehicles required for that operation. However, it is also obvious that it is somewhat difficult, if not impossible, to minimize the inconvenience to passengers and, at the same time, maximize the occupancy of individual vehicles.

An objective function that incorporated the maximization of bus occupancy and the minimization of user "inconvenience" might be used to solve the dilemma. Given several buses that could serve a new demand, each having about the same inconvenience value but each having a different number of passengers, then the new user would, under the control of the objective function, be assigned to the bus with the largest number of passengers. If the importance that is applied to the maximization of passengers is nonlinear, lightly loaded buses look much worse in proportion to heavily loaded buses, this strategy would likely cause buses to become empty so that they can be removed from the system. A discussion of such an algorithm will appear later in this paper in the discussion of the General Motors Research Laboratories work.

THE METHOD OF ORDERING THE PICKUP AND DELIVERY OF PASSENGERS

The Northwestern simulation package attempts to pick up new passengers as early as possible. That is, if a vehicle has one passenger already on board, the vehicle will attempt to pick up the new user before the delivery is made. The simulation package tries all combinations of scheduling the pickup of the new passenger as well as the delivery to his destination. The simulation package will choose the first position in the queue in which the pickup can be made and not violate any of the other levels of service guaranteed. The destination is handled in exactly the same manner, in that it is placed first in the queue in which it will fit without violating any of the other levels of service for the other passengers. Nothing is done to ensure that there is an optimum scheduling of the new passenger onto the vehicle. That is, the new demand (passenger) is scheduled to be picked up as soon as possible and will be delivered as soon as possible within the established constraints of the other passengers assigned to the vehicle. This, of course, means that someone who is already on the bus may have to wait until someone else is picked up and delivered before he himself will reach his destination.

The WABCO simulation operates on the priority basis. A passenger is picked up or delivered in the order of his priority. This priority is established in the manner that has been previously discussed.

In the M. I. T. CARS project the ordering of pickup and delivery is based on finding a point in the existing tour of a bus (the route the bus follows while picking up and delivering users) that will minimize the disruption of service to all current users. The function to be minimized is one involving projected pickup and delivery times of each current user and the link constraints of the bus's tour before and after the proposed pickup and delivery. There are 3 possible infeasible solutions to the pickup and delivery problem: (a) For a tour there are positions for the origin and destination that do not violate the link constraints but violate one or more of the service guarantees for the new demand; (b) for a tour it is possible to insert the new demand so as to satisfy its own service guarantees but at least one of the link constraints for that tour will be violated; and (c) solutions (a) and (b) are combined.

THE ABILITY TO HANDLE GROUPS OF PASSENGERS WITH COMMON ORIGINS AND WITH OR WITHOUT COMMON DESTINATIONS

The Northwestern simulation package does not specifically handle multiple origins or destinations. If multiple origins or destinations are to be handled, they would have to be treated as individual destinations. For example, if there were 3 people desiring to make a trip together from a common origin, this would be treated in the simulation as 3 separate demands for service. Also, each destination would be treated separately. Thus, there would be 3 destinations used by the simulation package. Three people, perhaps of one family, desiring to have the same destination might have to use more than one vehicle to obtain the service.

The WABCO report does not specify its method of handling multiple origins and destinations. It would seem from the report that they treat multiple origins and destinations in the same manner as the Northwestern simulation package.

In the M. I. T. formulation of the problem, a demand may consist of more than one person and is referred to as a passenger group. It would appear that for each passenger group there is a unique origin and destination. As a matter of fact, an example is given: "If two distinct demands have a common origin but not a common destination, the formulation represents their origin as two different non-negative integers which may or may not be sequential" (2). Associated with the formulation would be a list transforming these integers into some graphical representation of the pickup and delivery points. The possibility then exists that more than one bus would have to be used to satisfy the demand for travel from this one origin.

The system should be able to handle groups of passengers with a common origin and with or without a common destination. If this service is to be provided in off-peak periods where families might be using this service to attend movies, go shopping, or simply take a trip to visit the neighbors or relatives, then it is highly unlikely that a given family would desire to split into 2 or more vehicles for the trip. An algorithm to handle this situation would not be difficult to develop.

THE METHOD OF CONTACT AND THE FREQUENCY OF COMMUNICATION WITH INDIVIDUAL VEHICLES

The Northwestern simulation package assumes continuous contact with all vehicles operating on the system. There was no proposal as to the methods of contacts as far as electronic equipment is concerned. Essentially the WABCO report also assumed automatic vehicle monitoring. WABCO, having problems with the General Purpose Systems Simulations (GPSS) programs, used a negative time feature to account for automatic vehicle monitoring. The WABCO report suggested the possibility of 2-way radio communications as a means of achieving this constant monitoring of the vehicle on the system.

M. I. T. looked into 2 possibilities: (a) continuous location of the vehicle and (b) discrete location of the vehicle. Under continuous location, the vehicle path would be monitored at all times during the simulation and thereby allow instant reassignment of the

vehicle to pick up or deliver passengers. The feeling was that if vehicle monitoring is continuous, it may be possible to improve the routing policies by using intermediate assignments of new demands between vehicles. Under a system where only the discrete location of the vehicle is known, one does not have the capability of making an intermediate assignment or reassignment because the precise location of the vehicle is only known when passengers are either picked up or delivered.

The ability to communicate with the vehicle on demand is important to the efficient operation of the system. New users could be assigned vehicles and those vehicles rerouted if vehicles could be located when desired. If, on the other hand, an assignment cannot be made based on the vehicles' current locations, then the new user may suffer a delay in both his pickup and mean destination arrival time. Current users' travel time would likely be increased because a less desirable vehicle, in the sense that the vehicle had to be diverted to a greater extent, was assigned to pick up the new user. The operator or system suffers because the assigned vehicle may be required to travel farther out of the way thus increasing vehicle mileage and lowering the demand per hour that a vehicle can serve. The net result for the system would be an increase in operating cost.

The communication between the vehicle and control center will, in general, be nonvoice in an operational system. Vehicle location would be through the transmission by the control center of a coded signal, a different code for each vehicle; the vehicle would respond with a signal that may indicate the vehicle position. Routing information could also be transmitted by a coded signal causing a display or printout of where the vehicle is to go if the vehicle is being rerouted or how to get to the next stop in its tour. The vehicle might transmit a signal to the control center on arrival at a stop.

Voice communication would only be used in special cases, e.g., vehicle breakdown, passenger illness, or driver illness, because of the time required to transmit the routing information and the cost of the personnel at the control center that would be involved.

THE METHOD OF DESCRIBING THE STREET NETWORK CHARACTERISTICS OF THE AREA TO BE COVERED

The Northwestern package used a simple, 1-mile square grid. This grid was in turn divided into 100 basic units that represented intersections of blocks. Equal travel times were assumed on all links of the network.

The WABCO simulation also used a square grid. Their square grid ranged from a 1- by 1-mile square up to 5 by 5 miles. However, the grid unit size varied from one-tenth to one-quarter mile. As with the Northwestern simulation, the WABCO origin and destination points occur at grid intersections. The link travel time appeared to be uniform over the entire area.

The M. I. T. work of an earlier date, primarily the METRAN work, was based on a rectilinear grid of from 1 by 1 mile to 3 by 3 miles (4). The current work (2) discusses a network that is based on airline distances between points, using the reasoning that the specific street network under study is not pertinent to a grasp of the fundamental algorithmic concepts.

It would seem that the idea of simply describing a grid system with all of the links having the same travel time, or using airline distances, is very unrealistic. At a very minimum, a network description should be made in which one would be able to describe at least the major arterial street system by zone or by areas within the area to be serviced. This would conform more closely to present techniques used in the assignment package of most transportation plans. In, for example, certain areas in which there is limited access to river crossings, this would be a definite constraint on the scheduling and operation of a demand-type service. Therefore it would seem that, to have any accuracy or relate to a real-life situation, some form of existing street network should be described to the simulation program.

THE LOCATION OF VEHICLE TERMINALS

All 3 simulation studies locate the vehicle terminals in the middle or center of the study area. All 3 simulation projects use only one terminal from which to generate or dispatch vehicles.

The location of the terminal or terminals is very important to the performance of the system. If only one terminal is used, then the pickup time guaranteed will be a function of the time required for a vehicle to travel from that terminal to the most distant (in time) point in the area. For most areas this will be the corners. In a 2- by 2-mile area and with a vehicle traveling at an average velocity of 20 mph, the time for the trip might be 6 minutes, which seems to be a reasonable waiting time. On the other hand, if the area is 6 by 6 miles, the travel time for the same vehicle might be expected to be 18 minutes. If 6 minutes is the desired and, therefore, guaranteed pickup time, then something must be done. It is unlikely that the velocity of the vehicle could be increased to 60 mph, leaving only the possibility of additional terminals. Where these terminals will be located and the exact number required will be a function of the area to be served, i.e., shape and size, the level of demand, and the distribution function of the demand.

THE DISPATCHING POLICIES

In the Northwestern simulation package, when all of the vehicles on the grid cannot service an incoming call, then and only then is a new vehicle dispatched from the terminal to service this call. This vehicle will not be dispatched until after all of the other vehicles have been rejected.

The WABCO simulation designates a special (extra) vehicle that handles particular situations. When WABCO's 3 vehicles on the system cannot service a given demand for service, then the extra vehicle handles this individual demand. Each individual demand that cannot be serviced by the other vehicles is assigned a special waiting time measured by 1 unit for 3 minutes of wait, 1 unit for 2 minutes, and 1 unit for 1 minute of wait time. Once the extra vehicle is on its way to pick up a passenger and if there is a new demand located on the way to this origin, he also will be picked up. Essentially, the extra vehicle uses an algorithm that is designed to handle the longest trips and those waiting the longest.

In the CARS project a bus is dispatched if, and only if, none of the other vehicles in the system can service the demand. When a demand is made on the system, the vehicles are scanned to determine which vehicles can satisfy the demand. If none of the vehicles can satisfy the demand, that is, if guarantees will be violated for the new user or current users, then a new vehicle is dispatched from the station.

In regard to the dispatching policies, given that there are no vehicles on the system that can service the demand, then a vehicle from a terminal nearest to the incoming call should be dispatched to service the call. However, there might be some merit to having one or more vehicles that could be responsible only for servicing those calls that occur in an extreme situation and could not be serviced by any of the vehicles on the system. Also there might not be any additional vehicles available for dispatching in the terminals. If the scheduling algorithms work properly and everything is performing as it should, then it would seem that only very rarely would a situation such as this occur. An application of a sensitivity analysis would allow for evaluation of the number of times an extra vehicle designated only for handling extreme cases would be required.

THE PROPOSED LEVELS OF SERVICE

The Northwestern simulation package had 3 items included in the level of service—a minimum and maximum pickup time, and a maximum travel time. The minimum pickup time was automatically set at 1 minute; from the time that an individual placed his call he was assured that a vehicle would not pick him up for at least 1 minute. The maximum pickup time guaranteed the passenger that he would be picked up before a specified time limit has elapsed. The maximum pickup time was arbitrarily chosen to be 6 minutes. The maximum travel time was a linear function.

$$\text{Max travel time} = \begin{cases} K\,n, \text{ for } n \le n' \\ T + e\,n, \text{ for } n > n' \end{cases}$$

where

n = the number of links between origin and destination (a link is 1 block long);
n' = a control parameter constant set equal to 10 links;
K = a control parameter constant that equals 1 minute per link;
T = a control parameter constant that equals 5 minutes; and
e = a control parameter constant that equals one-half minute per link.

The 3 levels of service were guaranteed to each individual demand for service. At no time were any of these levels of service violated. That is, 100 percent of the demand would be assured these levels of service.

The WABCO guaranteed service time dealt with an assured total time that includes the waiting time. This time varied from 2 times the automobile driving time to 6 times the automobile driving time. The automobile driving time was assumed to be based on a 20-mph average speed plus a fixed value of 2 minutes. In the WABCO simulation each passenger was not guaranteed that he would have a given "phone to destination" time. However, in the simulation runs, 95 percent of all passengers were served within the guaranteed time.

The M. I. T. simulation work originally was for a square 2 by 2 miles and with a grid street pattern; this apparently was for the "many-to-one" algorithm. Vehicle speed was 15 mph between stops, each vehicle had a capacity to hold 6 passengers, the waiting time constraint was 15 minutes, and there was a time constraint for travel time that was a function of the distance of the trip. The assumed time for unloading and loading of passengers was 10 seconds. Results were not given for the "many-to-many" algorithms in this current report (2), although one would expect that the time constraints and the criteria used for calculating travel time would probably not change.

It is difficult at this point in time to put definite values on the various levels of service. In fact, an in-depth evaluation needs to be made to ascertain what levels of service would be compatible with the majority of potential users of a demand-scheduled service. This is presently being done (5), and it is hoped that after an evaluation is made absolute quantitative values can be attached to the various levels of service. It can easily be argued that different times of day would require different levels of service, different types of trip purposes would require different levels of service, and different geographic areas of operation might also require different levels of service. The point to be made is that levels of service depend on a variety of factors and these levels of service need to be evaluated in terms of the many influencing factors.

THE GENERAL MOTORS RESEARCH LABORATORIES SIMULATION

The General Motors Research Laboratories simulation will try to add to the development of a demand-responsive system simulation procedure. They are using a real city with its associated street network and travel data. The travel data are based on survey data, trip origins and desinations, of the case study city. The street network is also for the case study city and was coded from maps of the city. The network is divided into 2 network types, primary and zonal or secondary. The primary network contains the major streets in the city and the zonal boundaries. The zonal network contains the streets within each of the neighborhoods that the system will serve. Each zone covers an area of about one square mile. A minimum path routine may be used to determine the route and travel time between stops to pick up and/or deliver passengers. System performance or service level is in general maintained through system constraints such as waiting time and travel time guarantees that must be met for both current users as well as the new demand.

The selection of a vehicle to pick up new demands will be based on a function similar in many respects to that developed by M. I. T. The current function includes 4 weighted criteria as of this writing. These criteria are as follows:

1. An attempt to minimize the increase in travel and waiting time to those presently assigned to the system;
2. The desire to keep the waiting time of the new demand to a minimum and an attempt to minimize travel time for the new demand;

3. A parameter that aids in operations of the system and that if used exclusively would minimize the deviation of a vehicle from a given path; and
4. A parameter that will aid in reducing the number of buses in the system.

The weighted summation of the quantities relating to these criteria is, in effect, the cost (in time) of providing service. A cost increase is experienced if the new demand is assigned to a bus under consideration and should, it seems, be minimized on a system-wide basis.

The value used for the weights may be arrived at by various means. Clearly, once the system performance levels were set, the necessary values for the weights to make the system cost the least to the user could be determined.

On the other hand, if one were to consider the desires of the potential customer, by survey, then the weights and system constraining limits could be established and used to determine system performance. Presently work (5) is under way at the General Motors Research Laboratories that will provide quantitative measures of these values.

Using the function, all possible points in a bus's tour will be investigated to determine where the new demand might be picked up and delivered while meeting the guarantees provided current users. Then, that bus and those positions in the bus's tour that result in the minimum value for the function will be used for the demand.

For purposes of the simulation, the location of any bus may be assumed to be found automatically by sending a coded signal to the bus; this would cause the onboard radio equipment to respond. The returning signal is then analyzed and the bus location is determined.

The size of the current study area is approximately 36 square miles. Because of the desire to be able to pick up a new demand within 5 or 10 minutes after a request for service, and the average speed on the street network is not likely to be greater than 20 mph, it becomes apparent that 1 station or terminal located in the center of the city will not suffice. At a speed of 20 mph, it would require 0.21 hour or 12.6 minutes to travel to the corner of the area from the center. Therefore, there will be more than one terminal if either the 5- or 10- minute pickup service guarantee is used.

The only time a new bus will be sent from the terminal or dispatched is when none of the buses currently in the area can service a new demand because of violation of user guarantees. In this case, a stored bus will be dispatched from the nearest terminal to the demand.

One problem that has received little apparent attention is how buses are taken out of the system. Several questions need to be asked: What criteria could be used to determine when a bus is to be returned? How does one get the bus sent back?

The current function attempts to get buses out of the system by making the assignment to lightly loaded buses less attractive given that all of the other parameters are nearly the same in value. In other words, if 2 buses can serve a new demand and the cost of this service is the same for the combined parameters (new user, current users, and operator), then the new user will be assigned to the more heavily loaded of the 2 buses. Without the additional parameter the objective function would tend to uniformly load all buses causing more to be in the system at any given time than necessary. In addition to the parameter in the objective function, a constraint is used to return buses to the terminal at the end of given times; i.e., after 4 hours on duty making pickups and deliveries.

The simulation is written in the IBM PL/I language using the Interim Time Sharing System (ITSS) as installed on the IBM 360/67 computer at General Motors Research Laboratories. The machine was picked because it supports IBM 2250 graphic terminals that will be used to monitor and interact with the simulation. The PL/I language was chosen because there was no other real choice; fortunately, one can do things in PL/I that are either difficult or impossible in other high-level languages.

CONCLUSIONS

A review has been made of the work that has been done by 4 organizations: Northwestern University, Westinghouse Air Brake Company, Massachusetts Institute of Technology, and General Motors Research Laboratories. There are many similarities

among the various algorithms as there are differences, which demonstrates that there is yet much to be learned in the area of demand-bus type systems.

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Appendix

The following tabulations give a brief comparison of the algorithms discussed.

	PICKUPS AND DELIVERY	PRIORITY FOR PICKUP AND DELIVERY
NORTHWESTERN UNIVERSITY	Starting with the closest bus review for possible assignment, if not possible, look at the next closest	First bus that can provide the required service. Meet both user and the new demand guarantees.
	No objective function	
WABCO	Starting with the closest bus review for possible assignment, if not possible, look at next closest.	Priority based upon distance from bus and O-D distance for pickup. Priority based upon distance from bus to destination and total time.
	No objective function	
MIT	Review of all vehicles is made to determine which vehicle can 'best' serve the new demand.	Concurrent with the review of all buses a review of positions in the tour of each bus is made. Those positions that minimize the objective function are saved.
GMRL	Review of all vehicles is made to determine which vehicle can 'best' serve the new demand.	MIT uses two terms without 'weights'. GMRL function uses four terms with weights for each.

	LEVELS OF SERVICE	GROUP HANDLING	VEHICLE SIZE
NORTHWESTERN UNIVERSITY	Guaranteed service. One to five minute pickup and a guaranteed delivery time that is a function of distance between the origin and destination (O-D).	None	3 - 8 seats
WABCO	Guaranteed service.	Not clear	5 - 20 seats
MIT	Guaranteed pickup and delivery time. On bus time two to three times auto travel time.	Passenger units which may be more than one person.	6 - 10 seats
GMRL	Guaranteed pickup and delivery time.	Passenger units	Under study

	NETWORK DESCRIPTION	LOCATION OF TERMINAL (vehicle)	VEHICLE CONTACT (Loc. and Com.)
NORTHWESTERN UNIVERSITY	Rectilinear Grid one square mile link length = .1 mile	One at center of grid.	Continuous (assumed)
WABCO	Rectilinear Grid (1 x 1 to 5 x 5 mile) link length = .1 to .25 miles	One at center of grid.	On demand
MIT	Airline (direct movement from stop to stop) up to at least a 3 x 3 mile area	One at center of service area	At discrete intervals or continuous
GMRL	Real city streets 4000 nodes and 10,000 + one way links	A function of 1. Demand level 2. Size of area 3. Pickup guarantee	On demand

	DISPATCHING POLICY	BUS REMOVAL
NORTHWESTERN UNIVERSITY	As needed, once a bus is in the system it stays. Demand constant.	No
WABCO	Up to three buses served most demands. A fourth bus was needed to serve long trips and waiters.	No
MIT	As needed, once a bus is in the system it stays. Demand constant.	No
GMRL	Buses will be sent as needed.	The objective function will attempt to remove unneeded buses. Also buses will be removed on periodical basis; i.e., after four hours duty.

Determining the Importance of User-Related Attributes for a Demand-Responsive Transportation System

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Satisfying the most important needs and desires of the users of a new system of transportation is an important objective of design. To fulfill this objective will require that more be known about user preferences and their relationships to transportation system design and that better tools be developed for enabling users to communicate their needs more freely. Getting relevant information from the users themselves about their preferences and needs is one important way to improve the ability to design better functioning systems that are more suited to human needs and requirements yet are within financial constraints or other limitations. This paper describes the psychological scaling techniques of paired comparison and semantic scaling and shows how they may be adapted to the transportation system design process to provide the designers with more comprehensive and more structured information about the importance users place on various characteristics of a new transportation system. It describes useful methods for constructing and conducting a home-interview survey based on these techniques and outlines various procedures for analyzing the survey data. Finally, the paper places the techniques within a broader effort now under way to develop even better approaches to the design, evaluation, implementation, and marketing of public transportation and other complex urban systems.

• THIS PAPER DESCRIBES an approach to the design and market research of a local area public transportation system concept called the demand-responsive jitney system (DJ). The approach considers the system from the user's (that is, the passenger's) point of view. Although obviously relevant to a system that is intended to be demand-responsive, we believe that a similar approach should be taken to the design of other public transit systems to help increase their attractiveness to the public, their use, and their economic viability.

The DJ system is demand-responsive, and would provide service where the passenger wants to travel and when he wants to travel. The DJ system would thus have some of the characteristics of a conventional taxicab system. However, to minimize costs of operation, passengers would share the use of the vehicle, and therefore the DJ vehicle would be somewhat characteristic of small buses, airport limousines, and shared taxis—a class of systems that may be called jitneys. As a hybrid between the taxicab and the bus, the DJ system is generically similar to demand-responsive systems previously described by General Motors and others under names such as dial-a-bus, Genie, and DART (1, 2, 3, 4, 5, 6).

Paper sponsored by Committee on Future Concepts and presented at the 49th Annual Meeting.

Perhaps the most obvious design aspect of demand-responsive systems like the DJ is the employment of extensive electronic systems for communication, computation, and vehicle location. Such equipment facilitates the allocation, routing, and scheduling of vehicles in response to demands for service. Economically, this strategy increases the capital cost of the system (relative to conventional bus and taxi operations) in an attempt to more effectively employ drivers and vehicles in a situation where costs are dominated by driver labor and vehicle operating expense. (The effectiveness of this strategy is being investigated now as part of a DJ system simulation effort, which is outlined in another paper (7).)

For passengers, the use of such electronic aids to vehicle allocation, routing, and scheduling promises to improve service relative to conventional bus operation and reduce costs relative to conventional taxicab operation. However, the design of the electronic equipment, the routing and scheduling algorithms, and the computer programs represent only a part of the overall design of a demand-responsive public transportation system from the user's point of view. It is our purpose in this paper to discuss the wide range of additional characteristics of a demand-responsive transportation system that may be of importance to potential passengers, and to describe methods for determining the relative importance to the passenger of each of these system characteristics so that the information gathered may be used as a guide to better system design and market analysis.

Although the declining use of public transportation systems can be attributed to many factors, one of the most important has been the inability of public transportation system operators, designers, and planners to adequately satisfy the changing transportation requirements of their potential customers when confronted with the competition of the private automobile. This is an important factor to consider because public transportation systems exist within a competitive, consumer-oriented market. In this competition, public transportation systems have not done well. As important as this may be for the redesign of existing systems, it is critical for new systems development: If these new systems are to be successful, they must be designed to provide service that is attractive and competitive within a growing and changing consumer market (8).

To achieve this end in new systems design, some initial steps must be taken. First, we need to improve the quality of information about users and their needs and preferences by improving our evaluations of the performance of existing systems from the user's point of view, by developing a better understanding of transportation as a human environment as well as a transporter of people (9, 10, 11, 12, 13, 14), and by increasing our capability to understand changing consumer needs in terms of new system characteristics. Second, we must increase our creative abilities to translate these needs, once determined, into new and more appropriate system designs.

This paper describes the use of attitudinal surveys based on psychological scaling techniques as a means of developing some of the relevant information about user needs and preferences for potential new systems. It also discusses how this information can be structured to be more useful to the transportation system planners and designers responsible for new system conceptualization, elaboration, and testing. More specifically the paper (a) cites the importance of developing adequate techniques for determining preferences, and outlines some basic criteria to be met by measuring instruments; (b) offers a way of structuring the information so that it can be made more useful for design; (c) describes the psychological scaling techniques of paired comparisons, with reference to Thurstone's Law of Comparative Judgment, and semantic scaling; (d) describes the procedures employed in designing questionnaires suitable to these techniques and for conducting a community-wide home-interview survey of user preferences relevant to the demand-responsive concept; and (e) describes procedures for analyzing the data and applying the results to such areas as design decision-making and demand estimation modeling.

Finally, to view these methods in proper perspective, it must be realized that the users of a public transportation system constitute just one of the groups of actors who determine whether a new system will be successful and acceptable. Other interest groups include, but are not limited to, the following:

1. The transit system owner or operator, who must realize a profit or be adequately compensated for his role;
2. The system employees and the unions that represent them, who must have adequate pay, job security, and acceptable work rules;
3. Competing bus lines or taxi operators, who may have to be compensated for loss of revenue or franchise violation;
4. Homeowners, who may object to the transit vehicles being operated through their neighborhoods;
5. Employers and shopping center proprietors, who may welcome (or be indifferent to) a system that makes their plant or store more accessible to employees or customers without their having to enlarge their parking lots; and
6. Political leaders, who must be sensitive to the reactions of all of the other actors if they want to remain in office, and who, in addition, must be concerned about the authorization and regulation of the new system.

The last section of the paper, therefore, presents some thoughts on the incorporation of the techniques and procedures described here into an overall program of system design and market research. This overall program is needed if we are to be ultimately successful in implementing various kinds of innovative systems, including new forms of transportation.

APPROACHING THE PROBLEM

Surveying the attitudes of consumers in order to measure their preferences toward transportation products, or to give the designer direction in making specific design decisions, is not new (15, 16). However, in constructing and using attitudinal surveys within an interdisciplinary design process, we have tried to give this idea more analytical and operational clarity.

Developing Adequate Techniques

It has been pointed out earlier that our concern is the system user (passenger). It becomes important that system designers be able to determine what the user's real desires, wishes, and wants are with respect to the transportation system as a total entity, and very specifically with respect to the design of certain service characteristics and hardware. The extent to which we are assaying the user's view of desired system attributes and the depth to which each is explored are, we feel, new to the process of the development of a public transportation system.

The methodology employed is derived from the field of experimental psychology. Most specifically it evolved from the branch of experimental psychology called "psychophysics" (17, 18). In psychophysics one attempts to quantify the relationships between physical stimuli (e.g., intensities of light) and the psychological experience (e.g., perceived brightness). Psychophysical methods are useful in determining lower and upper perceptual thresholds and in establishing the differences of physical magnitudes required for an individual to determine a just noticeable difference (jnd). These basic stimulus/response measuring techniques have been extended in the psychological field of psychometrics to assay more strictly psychological phenomena such as vocational interests, aptitudes, attitudes, and the like (19). Our use of the methods in the design of transportation systems from the user's point of view is directly comparable, as we are measuring attitudes toward various potential system attributes.

All psychometric devices, including those that were used in this study, must meet certain "standard" criteria if they are to produce meaningful results. Briefly, these are as follows:

1. Validity—In simplest terms, validity in a testing device means that the instrument does, in fact, measure what it says it measures. In our specific case the method must provide a measure of the importance to potential users of certain attributes of transportation systems.
2. Reliability—A measuring technique must be consistent. That is, assuming no change in the individual's actual attitude, the device must be consistent in repeated

measurements. If "waiting time" for transportation is very important on one measurement, the same result should be attained when the individual is retested for this particular attitude, assuming no personal change in opinion takes place. It may be noted that a measuring technique, psychological or physical, may be reliable without necessarily being valid. A scale on which the units labeled "inches" are improperly divided will give the same "length" each time a given object is measured, but note that the device is not really measuring "inches" as it says it is.

Certain other general criteria, while desirable, are not standard. Their use is more dependent on the researcher's specific needs and, in some cases, his patience. These include the following:

1. Quantifiability—In some research cases qualitative (descriptive) data are all that are either required or possible. Usually, one desires the ability to quantify the acquired data. In our study it was determined that it would be desirable to establish frequency of preference and preferential ranks to the characteristics being investigated, and to establish scalar "distances" between attribute preference ranks. Such information would facilitate the design effort in those cases where trade-offs might have to be made between closely competing characteristics.
2. Analysis Potential—Analysis of the acquired data should be a simple process. The data should lend themselves to computer manipulation. Their form should be such that they are testable for compliance with certain statistical prerequisites for analytic procedures that permit description, prediction, and probability statements relative to the attributes measured.
3. Objectivity—The term as used here implies 2 things. First, the technique should be free from "constructor bias." It should not be constructed with certain categories of alternatives omitted, making the resulting data show a decided preference in the direction desired by the test designer. Second, objectivity (in the general case) refers to the manner in which the psychometric instrument is scored. In the so-called "subjective" device (e.g., the Rorschach ink blot test) much interpretation must be done by the scorer. This means that he must be well trained and a professional in the field, thoroughly familiar with the established base lines for interpretation. In the objective techniques, scoring methods are such that simple instruction to the scorer is all that is required. In our study, wherein it was intended to use very large samples, the objective method was not only desired, but virtually mandatory.
4. Simplicity of administration—Where large-scale sampling is involved, much can be gained by having a psychometric device that is simple to administer. Respondent requirements should be simple and minimal. Instructions should be clear and brief. Ideally, the device should be so designed that it can be self-administered by an individual, or administered to a large group without the involvement of highly skilled personnel.

The 6 criteria for psychometric devices described are met by the methods of paired comparisons and linear (semantic) scaling used in our study. It is felt that these methods for determining user preferences have much to offer transportation system designers.

Making the Information Operational

In addition to developing a technique that would fit the criteria specified, it is important that the resultant information be useful to the designer. This means determining the level of information to be provided and finding ways to link it to other parts of the design structure. Some discussion is available in the literature about the ways in which different levels of information may be structured and tied together in order to create an operational model for design (20, 21, 22, 23, 24). Using these concepts as a foundation, a design model was developed particularly for the demand-responsive system.

This model is shown in Figure 1. It links together various conceptual levels of design information in a semilatticed network. Broad human needs, such as preservation, individual growth and development, and choice, are linked to more specific transportation system concepts, such as accessibility, diversity, legibility, comfort, and convenience. These concepts of performance can be further linked to specific system

characteristics, such as travel time, waiting time, hours of available service, the assurance of getting a seat, and the levels of privacy. When these characteristics are described in measurable terms, then each of us can begin to evaluate a given system in terms of our own specially weighted set of performance concepts.

System characteristics are in turn linked to specific design variables that control the levels of each characteristic provided in the system. Further, many of these variables can be interrelated and grouped in complexes, so that changing one will change others in the complex as well. These complexes can then be given names or identifiers of their own, such as routing and scheduling system, vehicle system, and information system. Finally, all the subsystems can be grouped together to form the overall concept of a demand-responsive system.

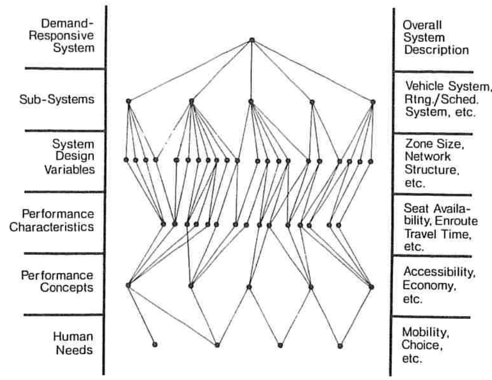

Figure 1. Design model for the demand-responsive system.

To make the data useful, system characteristics (such as travel time and waiting time) were organized so as to link with subsystem components (such as routing and scheduling and information), thus tying specific consumer responses about system characteristics directly to the subsystem of which these characteristics are a part.

Finally, being able to say that the user prefers one characteristic over another is not enough. To be most useful in the design process, the techniques must also identify (a) the "magnitude" of the differences between those characteristics that are more important and those that are less so and (b) the ranges over which the more important characteristics can vary and still be acceptable.

To do this, one might first establish, using the method of paired comparison, that a shorter waiting time was more important to system users than a lower fare. Then, using the linear (semantic) scaling method, one might explore the range over which waiting time could vary and still be acceptable.

THE METHOD OF PAIRED COMPARISONS

This discussion is largely based on Thurstone's original model for developing scale values from a given set of paired comparisons and also on works of Mosteller and Torgerson (25, 26, 27, 28, 29).

Suppose that a stimulus is presented to an observer. A stimulus can be anything that will produce some reaction or response in an individual. In this particular study, a stimulus is a characteristic of the demand-jitney service. The reaction of the observer to a stimulus or descriptor is defined as a discriminal process. Each time the stimulus is presented to an observer, a different discriminal process may be observed. However, if the same stimulus is presented to the same observer many times, some frequency distribution of the discriminal process will result. The postulate is made that the frequency distribution recorded will form a normal distribution on a psychological continuum. The most frequently recorded discriminal process is the mean of the distribution and is called the scale value. The standard deviation of the distribution is referred to as the discriminal dispersion. Different stimuli will result in different scale values and discriminal dispersions.

The object of giving different stimuli to an observer is to obtain the scale values of each stimulus, thus providing a ranking or scaling of the individual stimulus on a psychological continuum. Let the theoretical distributions of discriminal processes for any 2 stimuli be j and k as shown in Figure 2. (For example, the j stimulus might be the availability of air conditioning on a demand-jitney vehicle and the k stimulus might be the availability of coffee and/or soft drinks on a demand-jitney vehicle.)

Let S_j and S_k be the scale (mean) values and σ_j and σ_k be the discriminal dispersion (standard deviations) of the 2 distributions in Figure 2. If the 2 stimuli are presented

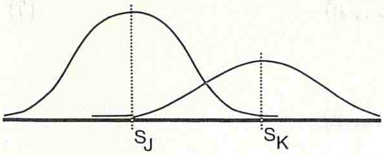

Figure 2. Distribution of discriminal processes for stimuli j and k.

to an observer, a discriminal process results for each stimulus. Let this discriminal process be D_j and D_k. The discriminal difference would be $D_j - D_k$. If the 2 stimuli are presented many times to an observer, the discriminal difference, $D_j - D_k$, would also form a normal distribution. The mean value of the discriminal difference can be shown to be

$$E(D_k - D_j) = S_k - S_j \tag{1}$$

The discriminal dispersion of the discriminal difference can be obtained as follows:

$$\sigma_k^2 = \Sigma(k_i - \bar{k})^{2/n}$$

$$\sigma_j^2 = \Sigma(j_i - \bar{j})^{2/n}$$

$$\sigma_{k-j}^2 = \Sigma\left[(k - j) - (\bar{k} - \bar{j})\right]^{2/n}$$

which reduces to

$$\sigma_{k-j} = \left(\sigma_k^2 + \sigma_j^2 - 2r\sigma_k\sigma_j\right)^{1/2} \tag{2}$$

where r = correlation coefficient.

In the paired-comparison application, each time the choice of 2 stimuli is presented to the observer, he judges which of the two is higher on the psychological continuum. Whenever $D_k - D_j$ is positive, the respondent has judged stimulus k greater than stimulus j. Likewise, if $D_k - D_j$ is negative, the respondent has judged stimulus j greater than stimulus k. Because the distribution is assumed to be normal, and the proportion of times stimulus k was judged greater than stimulus j can be obtained from the paired-comparison data, then $S_k - S_j$ can be determined from the areas under the standard normal distribution curve. This difference $(S_k - S_j)$ can be called X_{jk} and can be measured in σ_{k-j} units. Therefore, we can write the equation

$$S_k - S_j = X_{jk}\,\sigma_{k-j} \tag{3}$$

Substituting Eq. 2 into Eq. 3, one gets

$$S_k - S_j = X_{jk}\left(\sigma_k^2 + \sigma_j^2 - 2r\sigma_k\sigma_j\right)^{1/2} \tag{4}$$

Equation 4 is known as the Law of Comparative Judgment.

This form of the law cannot be solved directly as there are always more unknowns than equations. Some simplifying assumptions must be made in order to solve for the scale values S_k and S_j. For discussion here, it is assumed that the variances of the distributions of discriminal differences, σ_{k-j}^2, are all equal. Then Eq. 4 is reduced to

$$S_k - S_j = CX_{jk} \tag{5}$$

Separate equations for each stimulus can now be written. The set of equations would be

$$S_k - S_j = CX_{jk} \quad (j, k = 1, 2, \ldots, n) \tag{6}$$

Using observed data, one has X_{jk}' as estimates of the true X_{jk}. The observed X_{jk}' is used to obtain estimates of the true scale values, S_k and S_j. Allowing the unit of measurement of the scale values to be equal to unity, one then reduces Eq. 6 to

$$S_k - S_j = X_{jk} \quad (j, k - 1, 2, \ldots, n) \qquad (7)$$

Let

$$X''_{jk} = S'_k - S'_j \quad (j, k - 1, 2, \ldots, n)$$

where S'_k and S'_j are estimates of the true scale values. If the data were errorless, the derived X''_{jk} will equal the observed X'_{jk}; with observed data, they will be different. A set of estimates of the scale values of the stimuli for which the sum of the squares is a minimum is desired, where

$$SS = \sum_{j=1}^{n} \sum_{k=1}^{n} (X'_{jk} - S''_{jk})^2$$

Because $X''_{jk} = X'_{kj}$ and $(S'_k - S'_j) = -(S'_j - S'_k)$, the rows can be omitted. Now differentiating the elements of each column with respect to S'_k, one has

$$\frac{\partial SS}{\partial S'_k} = -2 \sum_{j=1}^{n} \left(X'_{jk} - S'_k + S'_j\right) \quad (k - 1, 2, \ldots, n)$$

Setting $\frac{\partial SS}{\partial S'_k}$ equal to zero, then

$$\sum_{j=1}^{n} S'_k = \sum_{j=1}^{n} X'_{jk} = \sum_{j=1}^{n} S'_j \quad (k - 1, 2, \ldots, n)$$

Dividing both sides by n,

$$S'_k = 1/n \sum_{j=1}^{n} X'_{jk} + 1/n \sum_{j=1}^{n} S'_j \qquad (8)$$

If the origin is at the mean of the estimated scale values, Eq. 8 reduces to

$$S'_k = 1/n \sum_{j=1}^{n} X'_{jk} \quad (k = 1, 2, \ldots, n) \qquad (9)$$

From Eq. 9, it is seen that the estimated scale values can be obtained by averaging the columns in the X'_{jk} matrix. This least squares solution requires that all of the cells in the matrix be filled. Certain other techniques exist for finding estimates of S_k when there are incompletely filled matrices.

The discriminal process from a single observer repeating his judgment many times has not been considered. However, in applying this law, one has a discriminal process reported by many individuals. To overcome this weakness, Thurstone argues that, for a given stimulus, extreme judgments for that stimulus are less common than those at or near the mean judgment for the whole group.

In the method of paired comparisons, each respondent has only to judge whether a given attribute is preferred over some other attribute. The method of paired comparisons does allow for a final scale to be developed, which is an indication or measurement of the relative importance of all the attributes considered. However, one is somewhat restrained in the amount of statistical inference that can be attached to the linear separation of attributes on the derived scale.

Linear (Semantic) Scaling

The semantic-scaling method was used in this study to explore respondents' attitudes toward certain selected engineering design alternatives that might be implemented in an effort to provide the system characteristics that had been scaled from the responses to the paired-comparison questionnaire.

In this quantitative judgment approach, the respondent is required to rate each individual design alternative (stimulus) on a specified linear scale. (In this study, the linear scale ranged from 1 to 7.) There are several underlying assumptions inherent in this procedure.

1. The respondent is assumed to make direct quantitative judgments as to the amount of desirability (or dislike) of each design alternative.
2. The respondent's scaled (indicated) response is assumed to reflect the subjective value (to the respondent) of the characteristic being scaled.
3. Any variation in reporting (over many respondents) will be treated as error. This results in the use of the mean of the responses as the best estimate of the scale value of each design alternative.
4. With the exception of this variation or error involved, the mean of the respondent's reporting is taken as the scale value of the alternative on a linear continuum.

There are many ways in which the data can be analyzed to give a description of the quantitative measurement of attributes on a linear continuum. Specifically if we let

f_{jk} = frequency with which alternative j was rated within category k, and
C_k = category (or point on linear scale) where alternative j lies,

then

$$S_j = \sum_{k=1}^{n} C_k f_{jk}/N$$

where

S_j = the best estimate of the scale value of alternative j,
n = number of categories, and
N = number of respondents.

In addition to the scale values, one can, of course, determine the variance for each scale value. Thus some further statistical applications can be made to the scale values developed on the linear continuum. Additional statistical tests can then be made relative to the linear distance between attributes.

These 2 techniques, the method of paired comparisons and linear (semantic) rating, are used to complement each other. They are further used for statistical estimation of the relative importance attached to selected attributes. Each method provides a usefulness that is unique. The combination of the two makes for a more comprehensive analysis.

THE SURVEY DESIGN

Selecting and Grouping Characteristics

An important first step in the preparation of the questionnaires is to determine the list of characteristics to be measured. Ideally, one would like to be unbiased when developing this list, free from any preconceived notions about what characteristics should be included. One might use various techniques to develop this list, including observation, interview, verbal response questionnaires, diaries or activity logs, and literature search. These techniques might be staged in order to proceed from a general level of problem identification to a more structured program of interviews and then to a final listing of characteristics. We have relied on past experience and literature search (30, 31, 32, 33, 34, 35, 36, 37, 38) as sources for the characteristics we have used.

Characteristics obtained from this search (well over 100) were grouped into 3 categories that determined how, or if, they would be used in the questionnaires. These were as follows:

1. Category 1—Important system characteristics whose specific form will be based entirely on professional analysis and judgment (cleanliness of the system, safety of the system, and the like). These were not included in the questionnaires.
2. Category 2—Important system characteristics for which relative user importances are desired (what is the importance of time spent traveling in the vehicle relative to the assurance of getting a seat, of having more chance of riding in privacy, or of paying a lower fare?). These formed the basis for the paired-comparison questionnaire.
3. Category 3—Important system characteristics for which a user preference for alternative design solutions is desired (should the method of fare payment be on a per mile or a zone basis; should service be around the clock or only at peak hours?). These formed the basis for the semantic-scaling questionnaire.

1. A shorter time spent traveling in the vehicle.
2. A shorter time spent waiting to be picked up.
3. Arriving at your destination when you had planned to.
4. Ability to adjust the amount of light, air, heat and sound around you in the vehicle.
5. More space for storing your packages while traveling.
6. A stylish vehicle exterior.
7. Freedom to turn, tilt, or make other adjustments to your seat.
8. The ability of coffee, newspapers, and magazines in the vehicle.
9. Small variation in travel time from one day to the next.
10. More phones available in public places used to call for service.
11. More protection from the weather at public pick-up points.
12. More chance of riding in privacy.
13. More chance of meeting people in the vehicle.
14. More chance of being able to arrange ahead of time to meet and sit with someone you know.
15. More chance of re-arranging the seats inside the vehicle to make talking with others easier.
16. A lower fare for passengers.
17. Making a trip without changing vehicles.
18. Less time spent walking to a pick-up point.
19. Being able to select the time when you will be picked up.
20. Longer hours of available service.
21. A vehicle whose size and appearance do not detract from the character of the neighborhood through which it passes.
22. Calling for service without being delayed.
23. Being able to talk to, and ask questions of, systems representatives when desired.
24. Easier entry and exit from the vehicle.
25. Room for accommodating baby carriages, strollers and wheel chairs in the vehicle.
26. The assurance of getting a seat.
27. Less chance of meeting with people who may make you feel insecure or uncomfortable.
28. More room between you and others in the vehicle.
29. Being able to take a direct route, with fewer turns and detours.
30. Being able to take routes which are pleasant or scenic.
31. More chance of riding with different kinds of people.
32. Convenient method of paying your fare.

Figure 3. System characteristics used in the paired-comparison questionnaire.

Constructing the Paired-Comparison Questionnaire

Thirty-two system characteristics were selected for use in the paired-comparison questionnaire (Fig. 3). Placing all thirty-two within one matrix would result in 496 paired choices, far too many to be included in a home-interview survey. To reduce the number of paired choices while still retaining those choices that were important and logical, 7 smaller matrices were developed, each related to a specific subsystem. In forming the matrices, care was taken to try to include only those characteristics that the designer might actually trade off in making design decisions. This had to be modified somewhat by the need of tying each of the matrices together with common characteristics, in order to perform statistical analysis. In the final questionnaire, 9 matrices were presented, resulting in 168 paired choices. A sample of the format used is shown in Figure 4.

Constructing the Linear Semantic-Scale Questionnaire

The paired-comparison questionnaire determined the relative preferences for each of the 32 transportation system characteristics selected for analysis. Some of these characteristics vary within themselves. For example, fare structures can range quantitatively over a wide continuum. Other characteristics might be variable only in a qualitative fashion (e.g., seating arrangements). It is the purpose of the semantic-scale questionnaire to explore, over a

GROUP C

This set of decisions deals with the interior design and structure of the vehicle that might be used in a new transportation system. For example, some of the choices will involve the amount of light, air, heat and sound around you in the vehicle, the exit and entry ways and several more.

Again, select your choice by circling the letter A or B, whichever is appropriate.

1.
A. Ability to adjust the amount of light, air, heat and sound around you in the vehicle.
or
B. Easier entry and exit from the vehicle.

2.
A. Easier entry and exit from the vehicle.
or
B. Lower fare for passengers.

3.
A. Space for storing your packages while traveling.
or
B. Accommodations for baby carriages, strollers and wheelchairs in the vehicle.

4.
A. Freedom to turn, tilt, or make other adjustments to your seat.
or
B. More space for storing your packages while traveling.

5.
A. Ability to adjust the amount of light, air, heat and sound around you in the vehicle.
or
B. More space between you and others in the vehicle.

Figure 4. Sample format for the paired-comparison questionnaire.

selected range, the magnitudes or varieties of qualities of twenty-seven of these characteristics. Question items were constructed describing various design solutions for each. The respondent was able to indicate the importance, acceptability, and desirability to him of the representative ranges or qualities of each system characteristic on a 7-point scale. Figure 5 shows a quantifiable characteristic and its scale. Figure 6 shows a qualitatively scaled characteristic.

Survey Implementation

The survey implementation design involved the identification of the survey area and selection of the initial sample population within that area; specification of the interviewing technique to be followed in administering the questionnaire; and determination of field procedures to ensure a specific sample completion rate.

The survey area was selected in order to be consistent with the total case study approach for the demand-jitney study, and is a suburban portion of a large metropolitan area. A sample size of over 1,200 households was chosen, and a modified probability procedure was used to select this sample. This procedure called for the random selection of over 200 households as the starting points for clusters of 6 households. These 6 households were located with respect to the respective starting point by using

7 Indicate on the scales below how acceptable it would be to you to wait for the Demand-Jitney the various amounts of time listed below. Assume that you are waiting at home.

FIVE MINUTES

1 2 3 4 5 6 7

Unacceptable I___I___I___I___I___I___I Very Acceptable

TEN MINUTES

1 2 3 4 5 6 7

Unacceptable I___I___I___I___I___I___I Very Acceptable

FIFTEEN MINUTES

1 2 3 4 5 6 7

Unacceptable I___I___I___I___I___I___I Very Acceptable

TWENTY MINUTES

1 2 3 4 5 6 7

Unacceptable I___I___I___I___I___I___I Very Acceptable

Figure 5. Semantic scale: a typical quantifiable item.

a specific skip interval method. Half of the households were designated to receive the paired-comparisons questionnaire, and half were designated to receive the semantic-scale questionnaire.

The questionnaires were designed to be self-administered by the respondent with the interviewer administering the introductory sections and helping the respondent begin work on the self-administered part in order to ensure comprehension and establish rapport. The interviewer then monitored the remainder of the questionnaire, answering any questions the respondent might have. If the interviewer detected any inability on the part of the respondent to self-administer the questionnaire, he would administer the entire interview. The interviewer attempted to establish an interview with as many members of the household of high school age or older as possible, conducting the multiple interviews either simultaneously or sequentially.

If members of a sample household could not be contacted initially, a maximum of 2 call-backs was made in an attempt to establish an interview at that household. If no

11 Occasionally it might be necessary to be able to identify one particular Demand-Jitney vehicle from others (e.g., at a common pick-up point at a shopping center). There are several ways in which this could be done. Indicate your preference for the various methods described below.

USE OF CODE NAMES ON VEHICLES

1 2 3 4 5 6 7

Undesirable I___I___I___I___I___I___I Very Desirable

USE OF A LARGE LETTER OR LETTERS TO IDENTIFY SPECIFIC VEHICLES

1 2 3 4 5 6 7

Undesirable I___I___I___I___I___I___I Very Desirable

USE OF AN IDENTIFICATION NUMBER

1 2 3 4 5 6 7

Undesirable I___I___I___I___I___I___I Very Desirable

USE OF COMBINATIONS OF A LETTER AND A NUMBER FOR IDENTIFICATION

1 2 3 4 5 6 7

Undesirable I___I___I___I___I___I___I Very Desirable

USE OF SYMBOLS SUCH AS CIRCLES OR SQUARES

1 2 3 4 5 6 7

Undesirable I___I___I___I___I___I___I Very Desirable

USE OF DIFFERENT COLORS FOR THE DIFFERENT VEHICLES

1 2 3 4 5 6 7

Undesirable I___I___I___I___I___I___I Very Desirable

Figure 6. Semantic scale: a typical qualitatively scaled item.

contact was made after these call-backs, the interviewer initiated a prespecified substitution procedure in order to replace that household in the sample. If a household refusal was encountered, a similar prespecified substitution procedure was utilized.

ANALYSIS OF SURVEY DATA

As discussed earlier, the paired-comparison questionnaire is composed of 9 separate matrices of pairings. Consequently, 9 independent psychological scales result from the implementation of this survey. These scales are in one sense indeed independent, because the attributes in each pair matrix were chosen as representative of actual trade-offs for a particular subsystem of the complete demand-jitney system. The independent scales are perfectly acceptable in this light.

In another sense, however, it would seem beneficial to achieve one universal scaling of all user-related attributes in which all of these attributes could be compared directly with respect to a common continuum. The purpose of this universal scaling might be to guide further research or development efforts, to aid in identifying areas of marketing emphasis, or to focus in on certain attributes for use as input to other models or studies. (One aspect of this latter use is discussed in this paper.)

Each of the independent matrices developed for use in the paired-comparison questionnaire has a minimum of 2 common attributes with at least one other matrix. This commonality allows a merging of any pair of scales because these 2 identical elements determine scale intersection points and the expansion/contraction factor needed to obtain a common unit of measurement. These pair mergings can be sequentially accomplished, allowing the formulation of one master scale.

Care must be exercised in combining the independent scales in this way. A respondent's perception of a certain paired choice might vary considerably according to the matrix (or closely related pairings) in which the choice is identified. Moreover, the very definition of an attribute might change as a function of the other attributes with which it is presented. Thus each scale combination must be carefully analyzed in order to minimize the inconsistency and inappropriateness that might be generated in such a move. These same considerations arise when using the common attribute pairs as measures of cross-validation between the separate matrices. Such cross-validation should nevertheless be performed as a check on internal consistency, keeping these limitations in mind.

Another essential validation procedure requires the use of pattern analysis routines in an attempt to identify repetitious artificiality in the questionnaire responses. Again, the application of this routine requires complementary investigation, with most final decisions relying on the judgment of the researcher.

It is very important to know when 2 scale ratings are significantly different in a statistical sense. This is important both for the paired-comparison technique in determining differences among relative preferences for a scale of attributes and for the semantic-scale technique in determining differences among preference ratings for related factors.

Most standard statistical tests of significance can be validly applied to the semantic scale data, because the individual distribution can be studied in detail. The question of significance is much more difficult with respect to the paired-comparison data, because certain assumptions are made in developing the scale. Nevertheless, certain methods of estimating significant differences can be applied. Two of these methods, an iterative technique and a specific application of a chi-square test, are discussed by Mosteller and Torgerson (28, 29). Torgerson also discusses certain statistical techniques to estimate the goodness of fit of the paired-comparison model. These will not be discussed at this time, but must be considered in a comprehensive analysis of the paired-comparison data.

A number of statistical analysis techniques can be applied to the survey data in addition to the previously discussed scaling procedures. These complementary studies can be rewarding in that new insights into the response patterns can be obtained without the need for further data collection efforts.

One very important analysis task is the determination of scale rankings as a function of demographic and economic measurements on the respondents. A powerful technique

applicable to this task is that of factor analysis (or principal-component analysis). Other applicable techniques include linear discriminant analysis and regression analysis. The data themselves should dictate which of these techniques is appropriate. Through the use of these techniques, user "classes" may be determined with respect to their attitudes toward demand-jitney system attributes.

Another very important task is the determination of a new set of factors, made up of linear combinations of the original attributes, that sufficiently describes the data variance, but that is perhaps of lower dimensionality than the original set of attributes. It may be particularly important to establish a set of orthogonal factors, so that system changes affecting only certain of these factors will not secondarily affect others, thus clarifying sensitivity analysis study. This task might be accomplished through the use of a principal-component analysis technique. Perhaps a more powerful investigation of attribute interrelationships might be achieved by using cluster analysis, which searches out response patterns as a function of the attribute set. At the other end of the complexity spectrum, simple multiple regression might prove adequate. In any sense, the determination of attribute interrelationships is crucial to a thorough understanding of user preferences.

APPLICATIONS

To Guide User-Oriented Design Decisions

One application of the data is as a guide to the designer making user-related decisions about the system's form. When thinking about routing and scheduling decisions, for example, the data provide him with information about those characteristics that potential users might emphasize, if they could make the design decisions. For example, the data may show that less time spent traveling in the vehicle and less time waiting were preferred to taking pleasant or scenic routes. The designer could then use this information to guide his decisions on vehicle size and speed, zone configurations, and passenger assignment. Even if a designer decides not to accept the preferences indicated by the survey, and wishes to modify their order of importance in some way, the information is still of value in helping him understand the existing situation from which he hopes to depart.

To Assist in Demand Estimation Modeling

The prediction of ridership on a new urban transportation system is certainly crucial to an estimation of the financial feasibility and as a substantial input into an evaluation methodology. Moreover, in order to comprehensively design such a transportation system, the demand estimation model must provide clear linkages to the design process in order that full implication of alternate designs on system patronage might be appreciated by the designers. The Transportation Research Department of General Motors Research Laboratories is developing a stochastic mode demand estimation model based on economic linear utility theory for use in the demand-jitney study. The relative importances, or coefficients, of the explanatory variables in the model will be estimated statistically from data collected through use of a home-interview survey. Both the inelastic (diversion from existing transportation modes) and elastic (latent demand) aspects of total demand for the demand-jitney system will be estimated using this model.

Certain of the user-related attributes listed earlier will be included as explanatory variables in the demand model so that user attitudes, as reflected in estimated usage, toward those design parameters can be determined. All of these attributes cannot be included as explanatory variables because of constraints in data collection such as questionnaire length, complexity, and content (in terms of presenting a realistic and meaningful differentiation in choice to the respondent). Simplicity is also desirable for many reasons.

It is intended that the relative psychological scale values of the attributes—the output of the paired-comparison survey—be used to screen out a reduced set of attributes for inclusion in the demand estimation model. The size of this reduced set will be dependent on analysis of the relative scale values. In particular, "natural" breaks in the

rank-ordered scale continuum will be sought in order to aid in determination of this reduced set.

INTEGRATION WITH DESIGN AND MARKETING OF CIVIL SYSTEMS

In closing, it is appropriate to point out that determining the importance of transportation system attributes from the passenger's point of view is part of a broader effort under way at the Transportation Research Department of General Motors Research Laboratories. This broader program is aimed at integrating more closely the system design and market research functions so that innovative civil systems, including new forms of public transit, can be more effectively implemented.

As we pointed out earlier, potential passengers make up only one of several interest groups who determine whether a new transit system will be acceptable and successful. Other interest groups include transit system owners, operators, employees, unions, competitors, homeowners, employers, retail merchants, taxpayers, politicians, transit equipment manufacturers, and others.

Implementation of a new system like the demand-jitney is possible only if an effective consensus can be reached among the various interest groups in the community as to the desirability of the new system, or at least its acceptability to each interest group. The necessity for such a consensus is a current fact of life for new civil systems such as transportation. This was not previously the case for transportation systems in our history and is not currently the case for many consumer products. However, if we want to apply modern technology to current social needs through the implementation of new civil systems, we must recognize that the "customer" for such a new system is not an individual, nor even some single group such as the "users" of the system no matter how big the group is, but rather a number of groups, with different interests and motivations.

The design of a civil system to achieve a consensus as to desirability and acceptance is a difficult process. The approach that is being taken in the General Motors Transportation Research Department program includes the modeling of the design, evaluation, and decision-making process for civil systems, and involves the following process:

1. Interest groups are identified;
2. Goals and objectives are defined for each interest group;
3. Controversial issues that may be posed by the new system are identified relative to each group, consistent with the group's goals and objectives;
4. The relative importance of each issue is determined for each interest group;
5. Relevance is established between issues and system attributes (that is, perceived system characteristics);
6. Relevance is established between perceived attributes and system design characteristics (both hardware and software);
7. A range of system design characteristics is considered, so that one may trace through the chain of relevance to forecast the impact, positive or negative, of design variations on the attitude of each group (this is similar to a sensitivity analysis);
8. Depending on the degree of precision to which this process can be accomplished for any interest group, one may forecast the degree to which some given system design is desirable, acceptable, or unacceptable to a particular interest group, and thus whether that interest group can be expected to support, be indifferent to, or oppose implementation of the new system; and
9. One may also search for that combination of system characteristics in a trade-off process, whereby no net negative impact is forecast for any interest group or, more hopefully, where system benefits are equitably distributed among all interest groups. This may involve fare strategies and compensation formulas.

It will be apparent that the foregoing process essentially involves an extension of the design process and the marketing function into the political science discipline. Determining the importance of transit system characteristics to passengers is only one step in this larger process. We believe this new and exciting work holds considerable promise of future application to a number of civil systems with complex implementation requirements.

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Simulation of a Computer-Aided Routing System (CARS)

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The computer-aided routing system (CARS) is a system designed to provide a taxilike service at a mass transitlike cost. It allows potential passengers to request service from their homes via telephone, with calls being processed by a central computer facility. The computer periodically executes a routing algorithm that assigns vehicles to passengers and communicates this routing information to the vehicles. The system is "real time" in that it will pick up a passenger shortly after a request and will deliver him to his destination within a guaranteed time (with a minimum number of deviations for collecting and delivering other passengers). The key to CARS is the routing algorithm. Because labor and vehicular costs are a major portion of the total system cost, an algorithm is required that can provide an effective dynamic service with a minimum number of vehicles. A variety of such algorithms has been proposed, but these algorithms cannot be evaluated in an analytic fashion. Hence, a comprehensive simulation model has been developed to test and compare these routing algorithms. The model facilitates the investigation of relationships between such parameters as number of vehicles and quality of service. This paper describes the methodology of the simulation model and the economic gains (in terms of the need for fewer vehicles) realized through its use. The use of an ARDS storage tube display to produce graphical output from the model is also discussed.

•CARS (computer-aided routing system) is a new concept in public transportation that is intended to provide door-to-door transportation service at a cost close to that of existing mass transit. The research and design of the system is being carried out by several academic departments and the special laboratories of M. I. T. This work was initially sponsored through the U. S. Department of Housing and Urban Development and is currently being supported by the U. S. Department of Transportation. About 70 people at M. I. T. are involved in the project. Initial research demonstrated the economic and technical feasibility of the CARS concept, and the current effort is aimed at the design and implementation of a prototype CARS system.

THE SYSTEM

CARS works basically as follows: Customers call for service from their homes (or some other origins) using telephones. These calls for service are received by operators who input the required information (e. g., origin and destination of trip, number of passengers, perhaps a billing number) into a digital computer. (In more advanced versions of the system, a user will be able to touch-tone his message, thus negating the need for human operators.) The computer is concerned with assigning a CARS vehicle to pick up and deliver each new passenger. The computer also automatically generates appropriate messages containing new assignments for the various

Paper sponsored by Committee on Future Concepts and presented at the 49th Annual Meeting.

vehicles. These messages are transmitted in digital form to the vehicle. Each vehicle has an encoder-decoder on board, which (a) translates the received digital messages into printed form for the driver, and (b) allows the driver to send messages back to the central computer. When a vehicle arrives to pick up a customer, the driver pushes a button that prompts the computer to send him information on his next stop. An emergency voice channel will also be provided for the driver. The system and information flows are shown schematically in Figure 1.

A customer will be picked up within 10 to 15 minutes of his initial call for service and once picked up will be taken reasonably directly to his destination. The customer will not generally be taken straight to his destination because the vehicle will have to make diversions to pick up and deliver other customers. Hence the service is very much like a shared taxi service: It is a centrally controlled door-to-door system that dynamically responds to requests and allows efficient sharing of vehicles. The design goal is that the ratio of the time spent in the system (i.e., elapsed time from phone call to delivery at destination) to direct driving time in a private automobile should average at most 2.5 and should, in no case, exceed 3.0.

To provide the taxilike service at mass transit fare levels (say, 50 cents per trip), the operating and capital costs must be kept as low as possible. Cost analyses indicate the most important cost components are the vehicles and the associated driver salaries. In some cases, these components constitute up to 75 percent of total system cost. Thus, one obvious way to keep the system cost low is to reduce the number of vehicles. It is here that the computer plays its most important role.

The hypothesis is that the computer can perform the assignment of new demands to vehicles very efficiently, in particular much more so than could a human multidispatcher system. Thus, savings in terms of number of vehicles (and associated drivers) are realized when a computer is introduced. Analysis shows the cost of the computer is far less than the savings in vehicle-related costs that are realizable by using a computer to perform the scheduling function. Put another way, a very good but extremely expensive transportation service could be offered by using many vehicles with, in the limit, a one passenger per vehicle system (or a standard taxi service). However, almost the same levels can be provided at lower cost by using fewer vehicles and coordinating them by computer.

Of course, having a computer to do scheduling is no solution unless an efficient algorithm to perform the customer-to-vehicle assignment exists. The development of such algorithms is one of the main tasks of the CARS research effort. These algorithms must work in an extremely complex and difficult environment that is stochastic in several respects. The demands, which appear randomly in time, have origins distributed probabilistically in geographic space. To compound the problem, the algorithm must be performed in "real time." All these factors plus further research have led to the conclusion that classical optimization solutions to the customer-to-vehicle assignment problem are not feasible (1). Although theoretically they could be formulated and solved for small problems, no reliable method for solving problems of realistic size has been found. This statement is true even if the real-time constraints under which the algorithm must operate are considerably relaxed.

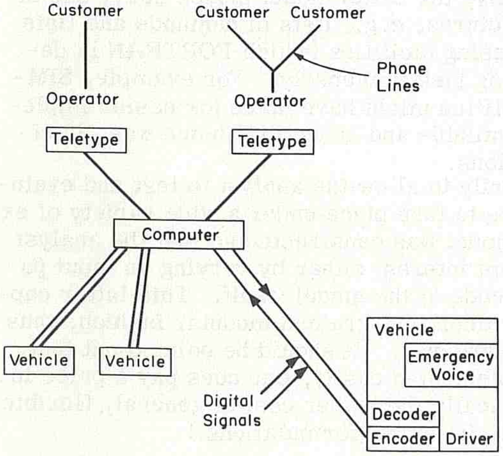

Figure 1.

Therefore, the algorithms that have been developed are heuristic in nature. When a new demand arises, the algorithm uses some heuristic rule to assign the demand to a particular vehicle and to appropriately insert the new origin and destination in the vehicle's route. At all times each vehicle

has a provisional route (i.e., a sequence of stops) associated with it. Provisional routes are updated with the occurrence of new demands, and a vehicle is not committed to a particular stop until the last possible moment.

Heuristics may be simple or complex, and this paper will not dwell on the heuristic rules themselves (11). There is a clear need for a means of evaluating and comparing different heuristics. Certainly no analytic model could predict the effectiveness of the heuristics, for much the same reasons as given for the failure of classical optimization techniques. Therefore, to help in the evaluation of the various heuristics, a simulation model for the CARS algorithms was developed. The remainder of this paper describes this simulation model and the results obtained from it.

THE MODEL

The model was implemented in FORTRAN and is an event-structured formulation. It is composed of 40 subprograms and is approximately 100,000 bytes in length (including data areas). Approximately 2 man-years of effort were required to design, develop, and test the model. Since its completion, about the same effort has been expended in exercising the model and in analyzing its results. Before work started on the development of the model described in this paper, several simpler CARS models were developed (10, 4). Thus, the staff was reasonably experienced with the issues before this effort began in earnest. Although the development of this progression of models was happenstance (the original funding was small and hence the effort was low-key), it is felt in retrospect that it was an efficient way to develop the model described here. In effect, an incremental approach was adopted. Rather than begin with a full-blown model, simpler models were developed first. The final model is considerably better as a result of this, and the approach is certainly recommended.

The question "Why FORTRAN?" might well be asked. At the outset, it should be noted that FORTRAN and GPSS were the only languages easily available to M.I.T. at the time of the model's development. FORTRAN was chosen by default because it was felt that GPSS did not lend itself to this model. The algorithms being modeled typically required a great deal of algebraic computation and, because the use of GPSS in such an environment is less than optimal, FORTRAN was chosen. Some evidence that this was the correct step exists. One of the authors (in a sadistic moment) assigned an extremely simplified subset of the CARS model (e.g., all customers going to the same destination) to a graduate class in simulation techniques with the proviso that GPSS be used. Even for the "easy" formulation, GPSS proved to be a difficult language with which to work. In fact, very few students produced a working model.

As mentioned, the large number of complex algebraic operations led to a choice of a compiler based language (FORTRAN) rather than an interpretive system (GPSS). Although the compiler approach is certainly sound, it is felt that FORTRAN is not the best language for this application. Specifically, the CARS model makes heavy use of complex data structures, especially list structures, e.g., lists of demands and lists of vehicles. A language with good list processing facilities (which FORTRAN is decidedly not) would have simplified the modeling task immensely. For example, SIMSCRIPT with its good data structuring capabilities might have made for easier implementation. However, SIMSCRIPT was not available and hence the choice was, in effect, made independently of these considerations.

The simulation model was designed primarily to allow the analyst to test and evaluate various heuristic rules. These tests were to take place under a wide variety of exogenous conditions. With this in mind, the model was constructed so that the analyst could easily implement the heuristic of current interest either by varying an input parameter or by making simple changes in the code of the model itself. This latter capability is realized by writing the model in a rather fine-grained modular fashion, thus allowing changes to be made in a straightforward way. (It should be pointed out that, although modularity allows changes to be implemented easily, one does pay a price in terms of efficiency of execution. This is basically the higher cost of general, flexible structures when compared to special purpose, inflexible formulations.)

In addition, the input to the model allows for the definition of a great many CARS environments. The following is a partial list of inputs and is given merely as an indication of the flexibility of the model:

1. Number of vehicles,
2. Vehicle capacity,
3. Average vehicle velocity,
4. Time distribution of demands (chosen from a predefined family or defined by the analyst),
5. Spatial distribution of origins and destinations (uniform or nonuniform),
6. Intermediate output intervals, and
7. Output options.

Considerable effort was expended in the model's design so as to provide the user a great deal of flexibility in his selection of random number strings. First, he can specify a separate seed for each of the random processes in the model. Second, he can specify whether the random number string or its complement string (obtained by subtracting the original number from unity) should be used in the simulation. These kinds of control over the pseudorandom processes in a simulation allow the user to do 2 things.

First, he can parametrically vary the controllable variables in the model (such as the heuristic rules themselves) while, in effect, eliminating unwanted randomness in the results. By using the same random number strings, he can duplicate the external features of the model from run to run while varying other parameters. In this way, positively correlated results can be obtained. This allows efficient (in terms of simulation run lengths) comparison of various strategies and also permits more rapid checkout and debugging when changes are made to the model.

Second, the analyst can achieve a complementary pair of runs by holding the parameters of the model constant and running the model twice, first with standard (uniform 0, 1) strings of random numbers and second with one or more of the random strings complemented (6). In this way, it is possible to obtain pairs of negatively correlated runs. The variance of the results obtained by summing the results of the 2 runs and dividing by two is generally less than the variance of a single run of twice the length, and hence efficiency gains can be realized. The initial work in this area has been quite encouraging.

To summarize, the model allows the analyst to conveniently experiment with techniques of this sort by permitting flexible specification of the random number strings and hence of the probabilistic structure of the model.

Output is equally extensive with its volume easily controlled by the analyst. Its precise makeup is documented in another paper (2).

MODEL RESULTS

As explained in the preceding section, the model was designed to test and evaluate a variety of routing heuristics for possible use in a real CARS application. Its use was an essential component in estimating the economic feasibility of the system and, as such, was crucial to the research and development program. Before describing the experiments that were performed and the results obtained, it is important to understand the criteria for judging the effectiveness of a given algorithm.

The variables over which the algorithm exercises control are the cost to the user of the system and the service times (waiting time plus travel time) experienced by the users. The aim of an algorithm is to minimize both of these conflicting variables (lower service times are generally achieved by using more vehicles hence increasing the cost). Different algorithms should, therefore, be compared in this 2-dimensional space of cost and time. An added complication is that the service times are random variables and different users of the system may be interested in different types of distributions. For instance, someone traveling to catch a plane is concerned primarily with the latest time he might arrive at the airport using this system, while a shopper might be much more interested in the mean service time. Clearly then, both the mean

and extreme worst service times are relevant. Considering these factors, the term level of service has been defined as the mean value of the ratio of service time to direct driving time taken together with the extreme worst service time resulting from the operation of a particular heuristic. The better the service is, the lower the level of service figure will be, though it can never be less than 1.0. Then the measure of effectiveness for a heuristic in a specific situation is the number of vehicles required to provide a given level of service. (Using number of vehicles rather than system cost is a valid approximation because, as described earlier, the dominant cost components in CARS are vehicle-related, including labor.)

Experiments using the model have been run for 2 main purposes:

1. To compare different heuristic rules in terms of the measure of effectiveness defined earlier; and
2. For a given heuristic, to predict how CARS would function in a variety of operating environments defined by varying the following parameters: (a) area size and shape, (b) demand level, and (c) desired service characteristics.

The general form of heuristic investigated involved attempting to insert the new demand's origin and destination in all possible positions on all vehicles' future routes. Associated with each attempt, a function Z is computed. This function measures the disruption caused by the insertion of the new origin and destination within a route. The insertion for which this function Z is minimized determines which vehicle will be assigned to the new demand. The route for that vehicle is then updated to reflect this.

In designing various heuristics, 2 factors have to be considered: (a) good service must be provided for current system users, and (b) the heuristic should ensure that service for future users will not be jeopardized. Considering just the current users, a possible selection criterion is

$$\text{Minimize } Z_1 = N_1e_1 + N_2e_2 + ST$$

where

N_1 = number of customer deliveries after the insertion of the origin stop for the new demand (Fig. 2),
N_2 = number of customer deliveries after the insertion of the destination stop for the new demand,
e_1 = vehicle detour time due to the insertion of the origin of the new demand,
e_2 = vehicle detour time due to the insertion of the destination of the new demand, and
ST = service time of the new customer for this insertion.

Then Z_1 measures the time that will be lost by all passengers currently on the system if the new demand is assigned in this manner.

Similarly, considering just the future demands, a possible selection criterion is

$$\text{Minimize } Z_2 = e_1 + e_2$$

This frees all vehicles as soon as possible thus enabling them to service new requests.

Figure 3 shows a comparison of these 2 criteria for a 3- by 3-mile area and for the same level of service. It is seen that the criterion Z_1 favoring current users gives better results though there is not very much difference.

Combining Z_1 and Z_2 produced the following criterion:

$$\text{Minimize } Z_3 = (N_1 + 1)\, e_1 + (N_2 + 1)\, e_2 + ST$$

Results of using Z_3 are also shown in Figure 3, and it is seen that very little

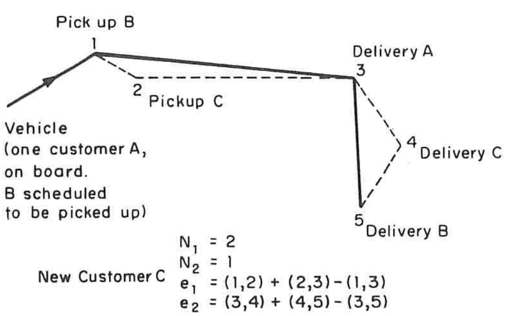

Figure 2.

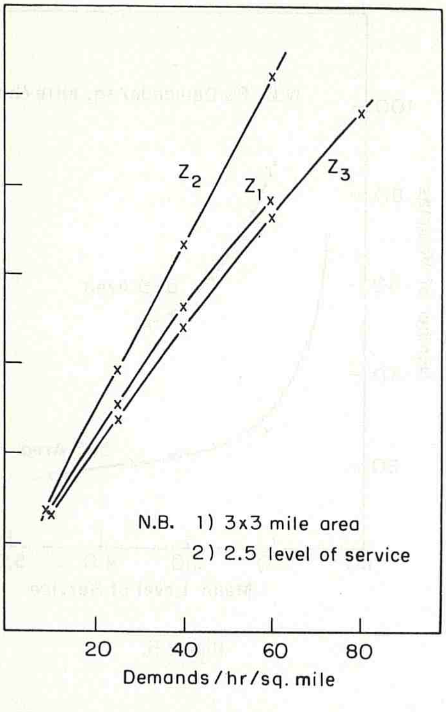

Figure 3.

improvement is obtained over Z_1. Of all heuristics tested to date, however, Z_3 produces the best results.

Figure 3 also illustrates one aspect of the second objective of the model experiments: the effect of parametric variation of the demand level on the cost of providing service. It is seen that, for any of the investigated heuristic rules and for the same area and level of service, there is an approximately linear relationship between the number of vehicles required and the demand level.

However, the vehicle productivity (in terms of passenger trips per vehicle-hour) does increase with increasing demand level as would be expected. This means that, the more people who can be persuaded to use the service, the lower will be the unit cost.

Figure 4 shows for the third (and best) heuristic rule the effect of operating in different area sizes at the same demand rate per square mile. The curves refer to demand rates of 25 and 40 per square mile per hour in a 3- by 3-mile area. Here, too, it is seen that the relationship is approximately linear with more vehicles required to service larger areas. In this case, however, the vehicle productivity remains approximately constant and independent of area size. This indicates that CARS does not stand to gain great economies of scale with respect to area size.

Figure 5 shows, again for the third heuristic, the variation of level of service with number of vehicles operating. The curves refer to 3- by 3- and 5- by 5-mile areas with demand rates of 25 per square mile per hour. The rectangular hyperbolic shape simply reflects the fact that a large number of vehicles can provide a good service, whereas a small number cannot. It is seen that in the 3- by 3-mile area, as the mean level of service approaches unity, the vehicle requirements increase rapidly while, at lower levels of service, small changes in the number of operating vehicles can have a sizable impact on the quality of service. These results indicate that CARS should aim at a level of service of about 2.5 (3).

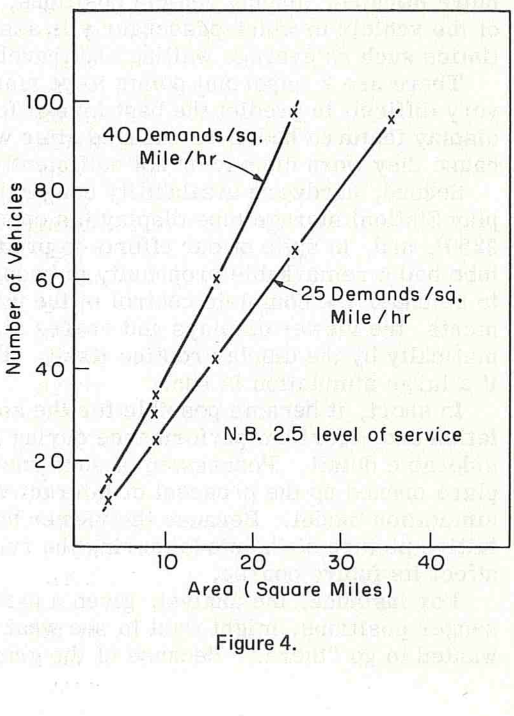

Figure 4.

INTERACTIVE CHARACTERISTICS OF THE MODEL

Many authors have expounded on the advantages of working with computers in an interactive (e.g., time-sharing) environment (5, 9). It is sufficient here to

say that it is worth a great deal to have the ability to interact with the actual operation of the model, especially in a simulation and more especially in the case of CARS where the question "What if this happened?" is always present. With these advantages in mind, the model was implemented and is currently operational on an interactive time-sharing system driven by an IBM 360/67 at M.I.T. This environment provides excellent development and testing aids and has unquestionably accelerated the research.

One very important way in which operating interactively was helpful was that the use of computer graphics became feasible. CARS is a classic example of the application of graphics. With demands arising randomly in space and vehicles moving about a large area, an on-line display is an extremely important aid to the intuition of the analyst. The mere printing out of results such as mean waiting time, for example, could easily mask the fact that the heuristic is generating pathological tours (e.g., around the block 3 times) that would be unacceptable to customers. Graphic display, on the other hand, easily uncovers these abnormalities. In general, the analyst using interactive graphics can ensure that the model's behavior "makes sense" without preprogramming extensive logic checks. In short, the task of model validation is made much simpler if graphics output is available. The model is designed to display, at predetermined but easily modified intervals, the most relevant aspect of the simulation as it has developed up to that point (i.e., display a passenger, display all passengers who have been waiting for t or more minutes, display vehicle positions, display vehicle x's route, display the route of the vehicle to which passenger y is assigned, and display system performance statistics such as average waiting and travel times).

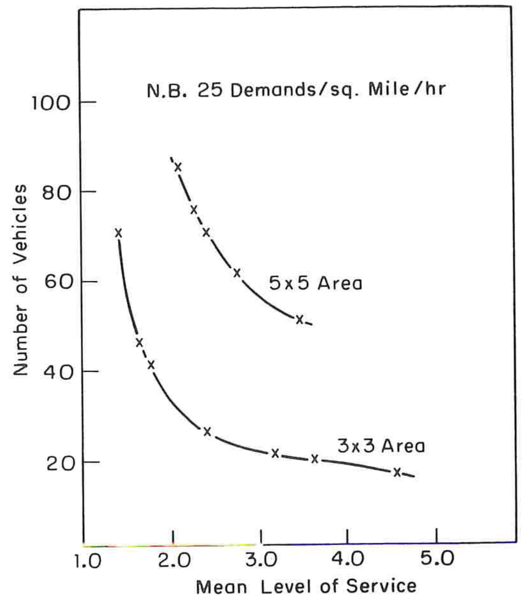

Figure 5.

There are 2 important points to be made about these display functions. First, it is very difficult to predict the best format for the display features. In fact, almost all display features had to be changed after we gained some experience in their use because they were clumsy or not sufficiently informative.

Second, hardware availability constrained us to use an ARDS (Advanced Remote Display Station) storage tube display (as opposed to a refreshed display such as the IBM 2250), and, in spite of our efforts to predict what would be a meaningful display, the tube had a remarkable propensity to becoming cluttered. Hence the display is designed to be under the complete control of the user. In what are felt to be meaningful increments, the viewer displays and erases at his discretion: Relatively little is done automatically by the display routine itself. The screen does, however, become cluttered if a large simulation is run.

In short, it became possible for the analyst to monitor the progression of the simulation and algorithm performance during the running of the simulation, and this in considerable detail. Possession of such knowledge as soon as the events involved took place opened up the prospect of interactive communication between the analyst and the simulation model. Because the viewer had a much more detailed and much more intuitive picture of the model during the run, he was now in a position to meaningfully affect its future course.

For instance, the analyst, given a particular situation in terms of vehicle and passenger positions, might want to see what would happen if a passenger originating "here" wanted to go "there." Because of the graphical output and the ability to input through

the display tube, the analyst can easily specify origins and destinations for the hypothesized new demand.

In addition to being able to manually specify a demand, the analyst can ask to see the choice of the current algorithm for that demand, before the model is committed to that choice. Thus if the algorithm wanted to assign vehicle x to passenger y, the analyst would be informed and would have the opportunity to override the algorithm's choice. That is, he could prevent the desired assignment and force the algorithm to use the second best choice. In particular, by simply repeating this procedure, the analyst can see, in decreasing order of desirability, all the algorithm's choices and then indicate to the model which should in fact be used.

With these capabilities in hand, the analyst truly has a new level of information available to him in readily understood form that permits him to delve into various aspects of algorithm performance. Because the display and interactive aspects of the model are under his control, he does not risk being deluged with more information than he can handle.

Future developments for the graphics additions to the model consist primarily of automatic entry into the graphic interactive mode whenever a specified set of conditions occurs (e.g., whenever mean level of service exceeds a given value). It is not known how the human engineering of such a feature will work out, but it should be possible to avoid too much automatic graphical output and thus keep the display useful.

In order to indicate the range and utility of the graphic display, photographs taken during an actual run (3- by 3-mile area, 100 demand/hour, 12 vehicles) are described. Figures 6 through 8 refer to time 45 minutes into the simulation run. Figures 9 through 15 refer to time 60 minutes and shortly thereafter.

Figure 6 shows all people who have requested service but have not yet been collected. Each dashed line joins the origin and destination for one of these waiting users. Associated with each user is a passenger identifier (the 4-digit numbers in the figure) and the time at which the service request was made (the 3-digit numbers).

Figure 7 shows the current projected route of vehicle 11. Next to each stop on the route is the corresponding passenger identifier, the letter P or D indicating pickup or delivery respectively, and the predicted arrival time at that stop. The vehicle is shown at its last reported stop, whereas it is in fact traveling to its first stop. Its projected route is to deliver demand 43 (currently on board), pick up demand 81, pick up demand 77, deliver demand 77, and finally deliver demand 81. Then, according to current plans, the vehicle will be empty and unassigned at time 65 minutes.

Figure 8 shows the activity of vehicle 11 in the immediate past. The labeling is the same as in the previous figure with the times being the actual arrival times.

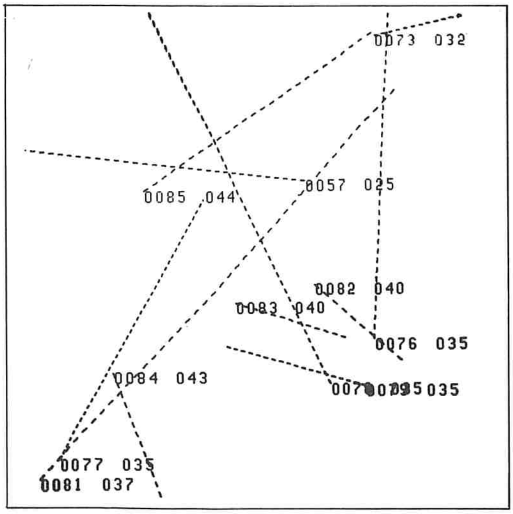

Figure 6.

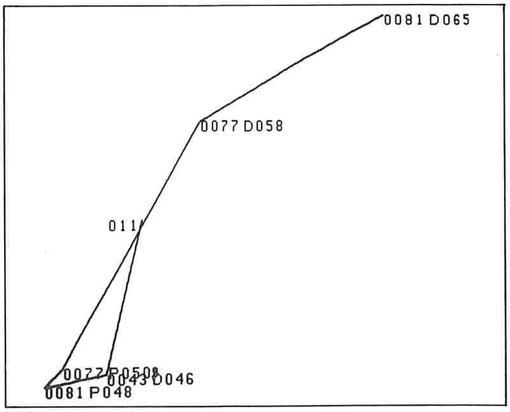

Figure 7.

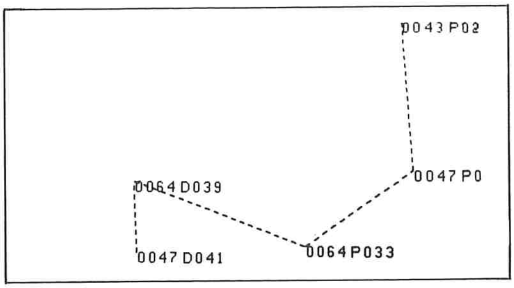

Figure 8.

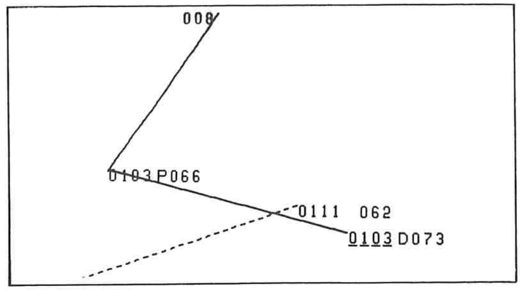

Figure 12.

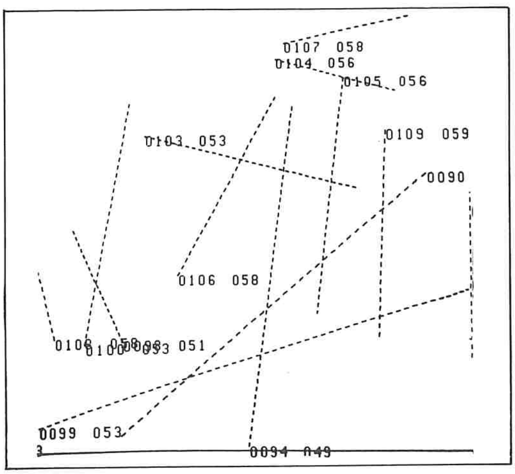

Figure 9.

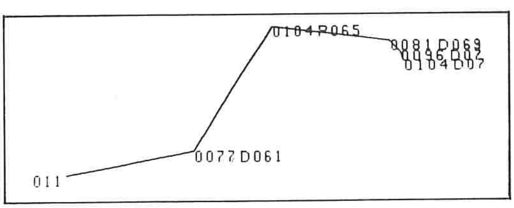

Figure 10.

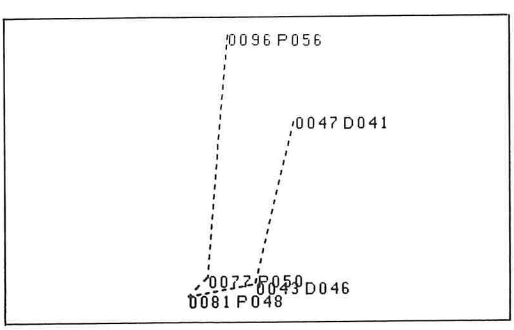

Figure 11.

Figure 9 at time 60 minutes shows all passengers waiting to be picked up.

Continuing to follow vehicle 11, Figures 10 and 11 show its current projected route and recent history respectively. Comparing these figures with Figure 6, it is seen that more stops have been added to vehicle 11's route since time 45. Specifically, passenger 96 has already been collected and the vehicle is now also scheduled to serve passenger 104. Consequently the expected delivery times of passengers 77 and 81 have been revised. This is, of course, a typical example of the system's dynamic response to changes in the demand state.

Figures 12 through 15 relate to the interactive aspect of the graphics in the model. In Figure 12 passenger 111 has been manually input through the screen (much as one would use a light pen) with the desired origin and destination points. Also shown is the assignment that is chosen as best by the heuristic. If the analyst did not interfere, the new passenger would be assigned to vehicle 8 and (as indicated by the underlining) would be collected just before passenger 103 was to be delivered.

Figures 13 and 14 show the heuristic's second and third choice of assignments respectively. Finally, Figure 15 shows the revised route of vehicle 11 (the heuristic's second choice) after passenger 111 has been assigned to it at the analyst's behest (at time 64).

This last sequence of figures demonstrates how the analyst can obtain an excellent idea of how the heuristic is actually functioning. In this way errors in both theory and implementation can readily be detected, and the insight of the analyst is deepened so that better heuristics can be developed.

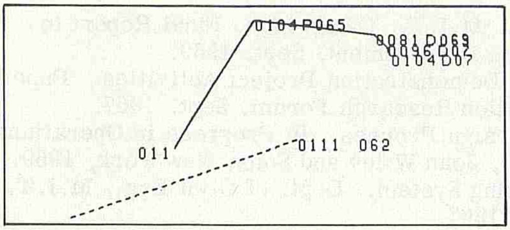

Figure 13.

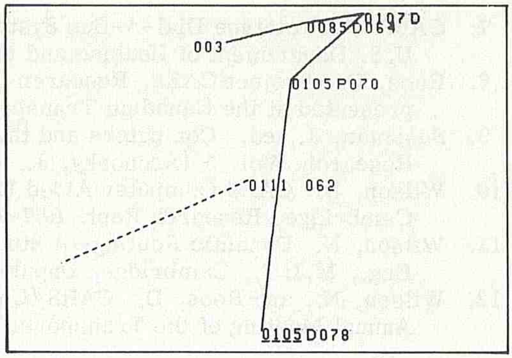

Figure 14.

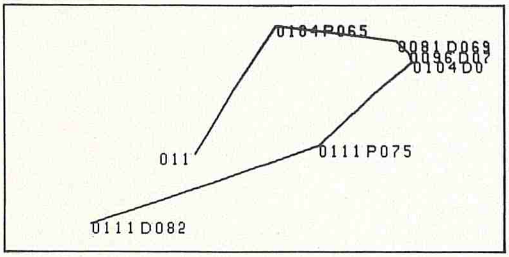

Figure 15.

CONCLUSIONS AND FUTURE DEVELOPMENTS

The model proved invaluable in demonstrating certain characteristics of the CARS system and justifying continued work to elaborate the concept. In particular it helped validate algorithmic ideas and indicate how the system might behave in a wide range of environments with variation of area size, demand level, and service characteristics. The model was used successfully to compare algorithmic choices and in this way helped to clarify to the analyst the operation of the system. The best heuristic based selection on both future and current system users with more weight on the latter. It was found that the system was not very sensitive to differences between several rational heuristics. The service should be more efficient at higher demand rates, but large service areas should probably be avoided.

Future developments include the simulation of particular geographical areas in which real street networks and expected demand patterns would be incorporated. A further major step forward would be the development of a complete CARS system simulation rather than the algorithm simulation that exists now. In the development of CARS, simulation is certain to play a vital role right up to (and indeed after) the first passengers are carried; in a complex stochastic system such as this, there is no alternative.

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